REPORT

ON

# INDUSTRIAL WASTES

FROM THE

# Stockyards and Packingtown

IN

CHICAGO

VOLUME II

1921

THE SANITARY DISTRICT OF CHICAGO

# REPORT

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# INDUSTRIAL WASTES

FROM THE

# Stockyards and Packingtown

IN

# CHICAGO

MADE TO THE BOARD OF TRUSTEES

THE SANITARY DISTRICT OF CHICAGO

JANUARY, 1921

OFFICES
STANDARD OIL BUILDING
910 South Michigan Avenue
CHICAGO

# REPORT

ON

# INDUSTRIAL WASTES

FROM THE

# STOCKYARDS AND PACKINGTOWN

IN CHICAGO

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## VOLUME II

JANUARY, 1921

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MADE TO THE

ENGINEERING COMMITTEE OF THE SANITARY DISTRICT

OF CHICAGO

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ALBERT W. DILLING, Chief Engineer
LANGDON PEARSE, Sanitary Engineer

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## LETTER OF TRANSMITTAL.

Chicago, January 20, 1921.

To the Honorable,

The Committee on Engineering,

Gentlemen:

For the past nine years this Department has been making a careful study of the sewage and sewerage conditions of the region known as the Stockyards and Packingtown, which drains into the East and West Arms of the South Fork of the South Branch of the Chicago River. During this period, from 1912 to 1918, a sewage testing station was operated at the outlet of the Center Ave. sewer into which comes much of the sewage from the packing plants.

On October 15, 1914, Mr. George M. Wisner, then Chief Engineer, made to you a report on the Industrial Wastes from the Stockyards and Packingtown in Chicago, in which was presented the data and results of tests up to that date. Since issuing that report, the scope of the original testing station was enlarged by the addition of the activated sludge process. Further investigations were made of the individual houses in Packingtown, at the request of the packers, to determine the flow and relative proportion of waste. Various investigations and reports have been made, developing the results of the testing station work into concrete form. All of this material is of value to the Sanitary District and to the Packers, and of great interest to others.

The construction cost of the original testing station was largely defrayed by a fund contributed by the various firms in Packingtown, the Union Stockyards and Transit Company furnishing the land at a nominal rental. The cost of the gagings and investigation in 1917 was also paid by the packers. In consideration of these contributions, a report was promised to the subscribers. The first volume was presented in 1914, the second volume I now have the honor to present.

Since the publication of the first report in 1914, great progress has been made, by conference with the packers, towards reaching a solution of the problem. The negotiations were necessarily shelved during the period of the war, but in the last twelve months have been resumed and pushed, with the result that the packers have offered to assume sixty per cent of the cost, if the Sanitary District will assume the remaining forty per cent. A suggested form of contract has been drafted and is now under consideration.

From the engineering standpoint, marked progress has been made. Based upon the experiments of the Sanitary District, and the experience of the packers at Chicago and Fort Worth, Dr. W. D. Richardson, representing the packers, agreed with our Sanitary Engineer, Langdon Pearse, that the activated sludge process was the most practicable for handling the sewage from Packingtown. The conclusions and recommendations were outlined in their joint report of April 16, 1917. Their estimates contained therein have been revised from time to time by our department. Further detailed surveys have been made of the territory in which the project is located, gagings have been made, and all information of value collected.

All our data indicates that the activated sludge method is

practicable and will handle the wastes from the entire packing and stockyards industry so that eventually no load of that character would be put upon the Main Channel of the Sanitary District. This requirement is essential, as we are now facing the definite exhaustion of the capacity of the channel by the growth of population and the limitation of flow from Lake Michigan.

Our desire for a community plant has been finally accepted by the packers. We believe it is most desirable because of the concentration of the operation in one locality and consequent ease of securing the best and most economical operation. We are hopeful that the developments in the technique of the activated sludge process will not only reduce the cost of operation but produce a marketable fertilizer of greater value than heretofore.

Our investigation clearly confirms our former statement that the sewers now existing in the Stockyards and Packingtown are inadequate and need rebuilding. The City of Chicago is proposing to construct a new sewer along Center Ave. We have undertaken the extension of the 20 foot conduit in 39th St. west from Halsted St. The extension of W. 39th St. from Halsted St. to Ashland Ave is being planned. Grade crossings are also involved. With these and the sewage treatment problem, an unusually complex set of engineering problems has developed in a comparatively small area.

At the present time, I believe it most desirable that a site be selected for the treatment plant, and the necessary intercepting sewers built, with screening apparatus to handle the entire flow. A liberal unit activated sludge plant should be installed and enlarged as rapidly as possible. In this connection every possible angle of economy in construction and operation should be investigated and tested from the start.

This report covers many phases of the engineering and treatment problems involved and represents the combined work of the Sanitary Division, under the direction of Langdon Pearse. To J. J. Newman, formerly Assistant Engineer, for field supervision during operation, compilation of the records and preparation of the report, together with original investigations, great credit is due. The investigations in the chemical and biochemical fields were carried on by Dr. Arthur Lederer, our former Chemist. To Dr. F. W. Mohlman, Chemist, and to L. C. Whittemore, Assistant Engineer, for compilation of records and final preparation of the report, due acknowledgment is made, as well as to the other

assistants in both engineering and laboratory work who have carried on the work.

I further desire to express my acknowledgment to George M. Wisner, Consulting Engineer, former Chief Engineer of the Sanitary District, under whose general direction the sanitary work was inaugurated in 1909 and the various investigations developed, and to E. J. Kelly, who succeeded him as Chief Engineer.

To the officials of the Union Stockyards and Transit Company as well as of the packing houses, all of which firms are listed in Appendix 2, thanks are due for hearty co-operation and assistance in carrying through the investigation.

In view of the injunction suit now pending in the Federal Courts to determine our right to take diluting water from Lake Michigan over and above 4167 cu. ft. per sec., our present endeavor to adjust all the lake level and diversion controversies, both national and international, and the condition of the Illinois River, which is steadily growing worse, in large part because of the spurt in the packing industry, I urge that your honorable Board of Trustees make every effort to arrive at a formal agreement with the Packers and Stockyards interests, so that actual work can be started upon a constructive plan. Improvement of existing conditions is imperative. Ample time has been given all concerned to consider the situation. Certain improvements can now be made at once. Greater expenditures for the complete improvement can be made from time to time on a descending scale of cost, I hope.

For many years tons of material have been thrown away as useless by the Packers. I hope soon, with the co-operation of all concerned, that a notable step toward utilization can be made and a commercial fertilizer produced from the material now polluting our Main Channel and the Illinois River.

Respectfully submitted,

ALBERT W. DILLING,

Chief Engineer.

# PACKINGTOWN WASTES

## IN CHICAGO

# Activated Sludge Tests

## 1915 to 1918

## GENERAL SUMMARY

### NOTE TO THE READER

**Pages 32 to 47 afford a technical summary of the results obtained in the activated sludge tests from 1915 to 1918.**

DEVELOPMENT OF STOCKYARDS AND PACKINGTOWN. For years Chicago has been the center of stockyards and packinghouse interests. A large community of plants has grown up in the vicinity of 39th and Halsted Streets on the south side, occupying over one square mile, with stockyards and packinghouses and including all the scattered plants, nearly one and one-half square miles. The industry has grown from small beginnings, with various shifts in location. In 1848, John B. Sherman started the Old Bull's Head stockyards at the corner of Madison Street and Ogden Avenue. This site proving unsatisfactory, a new site was selected at Cottage Grove Avenue and 30th Street, known as the Sherman Stockyards. In 1865, the site was again changed to a half-section bounded by 40th and 47th Streets, and by Halsted Street and Center Avenue, at that time largely a swamp far outside the city limits. At first, the yards covered 120 acres, with 2,000 cattle pens, which grew in 1901 to 340 acres with 5,000 pens.

From 1865 on, the industry developed in one central location. As nearly as can now be learned, drainage was into the south branch of the Chicago River, a very sluggish stream, utterly inadequate to receive the wastes of even a young industry. Complaints began early and continued in years, lessened somewhat by the endeavors of the packers to recover more completely the by-products. In the early days, the problem of disposing of the offal, resulting from the slaughter of cattle, sheep and hogs, was very troublesome. Even its value as a fertilizer was unknown. Blood was allowed to run

into the river, while heads, feet, tankage and general refuse were hauled out on the prairies and buried. A few began to dig up this material and convert it into glue, tallow, oil and fertilizer in small factories. For a while the offal was given to anyone who would cart it away. Various products of fair quality were made in small factories at large profits which attracted so much competition that buyers bid up the price of offal to a high figure.

With the perfecting of a direct heat dryer in 1877, the packers began to enter the fertilizer industry, making the profits for themselves. Gradually other by-products were utilized by the packers themselves, so that today practically every part of the animal is used in some way in factories belonging to the large packing houses. In the small houses, slaughtering largely for intra-state or local trade, early conditions still obtain. Blood, offal, and even tankage frequently are discharged into the sewers in a way not tolerated in the large houses. Today in the large houses, an attempt is made to save practically everything except the squeal, and even that the packers jokingly say is canned by a phonograph. In the pursuit of returns, grease was skimmed from the main sewer outfalls at Ashland Avenue (until diverted in 1917) and Center Avenue and from the immediate surface of the river.

The kill has gradually increased (Fig. 8), up to 1900, when the number of head slaughtered at Chicago decreased, because of the increasing number of western packing centers at Kansas City, St. Joseph, Omaha, Fort Worth, etc. But with the increased demand for food products due to the European war, the kill in Chicago jumped from 10,300,000 head in 1910 to over 14,000,000 in 1916.

IMPORTANCE OF LOSSES. The endeavor of the industry to secure economic recoveries has not, however, carried the efforts so far as to retain material of importance, not necessarily from the manufacturing standpoint, but from the standpoint of sewage disposal. There is still much material which passes away, in the aggregate several thousand tons a year, to which the practical manufacturer attaches little importance. To the sanitary engineer these wastes, containing large amounts of suspended matter with a liquid highly putrescible, are of great importance. For many years the belief prevailed that industrial waste of a highly putrescible character was concentrated in the region along the south fork of the Chicago River known as Bubbly Creek, yet no definite data had been found on which to base any recommendations for its treatment or use.

NEED OF IMPROVEMENT. Many sanitary engineers of standing have felt that the legal minimum rate of flow (namely 3.33 cu. ft. per sec. per 1000 population) prescribed for the Sanitary District by its charter was too low to care for the industrial load of the Main Channel in addition to the sewage of purely human origin. With the flow existing in the West Arm up to 1917, it was evident that sedimentation did occur both of the organic and mineral suspended matter. The velocities of flow were not sufficiently high to scour. In 1917 this arm was filled up from Ashland Avenue West and the sewage diverted. The condition of the South Fork has also been vastly improved by the construction of the 39th Street pumping station, and the use of the flushing pumps, but permanent improvement will not ensue until the quality of the waste discharged into the river is distinctly improved, and large amounts of suspended matter removed.

MAINTENANCE WORK. From time to time substantial deposits have been dredged out of the South Fork by the United States, the City of Chicago, The Sanitary District, and private corporations. The amount of material so removed has amounted to several hundred thousand cubic yards, since the opening of the Drainage Canal in 1900. A record of soundings in the West Arm, west of Ashland Ave., showed that over a period of thirteen years from 1895 to 1908, the shoaling had continued at a rate of 0.42 feet per year. In this dead end, fed solely by the Ashland Ave. and Robey St. sewers, and a little surface water from the original bed of the old West Arm east of Western Ave., the source of the deposits was at once evident. During the work preliminary to the opening of the conduit from the West Arm through Western Ave. to the Drainage Canal, the Sanitary District removed approximately 100,000 cubic yards of material from the West Arm west of Ashland Ave. Of this it is estimated that over 50 percent was typical sludge of sewage origin, in various stages of putrefaction.

EFFECT ON MAIN CHANNEL. In 1920 the total population of the Sanitary District was around 2,976,443, of which 2,757,572 drain into the Main Channel. Studies made of the industrial load show that Packingtown is equivalent to about 1,000,000 people in its effect; the Corn Products Refining Company at Argo to 370,000 people and the other miscellaneous industries to around 400,000 equivalent population. This makes a total load on the channel equivalent approximately to 4,500,000 people. Consequently Packingtown is a very large factor in the load. The present flow is

around 8,000 cu. ft. per sec. which is the legal minimum for 2,400,000 population. The present capacity of the Channel appears to be 10,000 cu. ft. per sec. or 3,000,000 population on a legal minimum flow.

PREVIOUS INVESTIGATIONS. Early in the history of the Sanitary District it was realized that something must be done to improve the condition of Bubbly Creek. In 1890 steps were taken by L. E. Cooley, then Chief Engineer, towards a comprehensive investigation covering gauging of sewers and chemical analysis, but little data was obtained.

Ten years later in the report of the sanitary investigation of the Illinois River and its tributaries (Illinois State Board of Health, 1901) Professor J. H. Long made a special report on the chemical and bacterial examination of the waters of the Illinois River and its principal tributaries. In this report he commented on the conditions existing in Bubbly Creek and the north branch of the Chicago River.

The investigations covered in the Report of Industrial Waste of October, 1914, were made in the period between January, 1911, and October, 1914. In these investigations all the practicable standard methods of sewage treatment known at that time were studied. The results of this work are summarized later.

COMPOSITION OF WASTES. Several thousand individual analyses of packinghouse waste have been made by the Sanitary District both on the houses and on the main sewers. The waste is much stronger in the day than at night. The analyses of day sewage have been averaged with the results given below, as compared with the normal domestic sewage pumped at 39th Street.

| Determination | Results in Parts per Million | |
|---|---|---|
| | 39th St. Sewage 24-Hour | Packinghouse Waste Day |
| Organic Nitrogen | 7.8 | 79.0 |
| Ammonia Nitrogen | 9.1 | 22.0 |
| Nitrite Nitrogen | 0.1 | 0.5 |
| Nitrate Nitrogen | 0.3 | 3.0 |
| Oxygen Consumed | 43. | 269. |
| Suspended Solids | 144. | 605. |
| Chlorine | 40. | 1,100. |
| Alkalinity | 212. | 291. |
| Biochemical Oxygen Demand | 121. | 990. |

DEFINITION OF ANALYTICAL TERMS. Sewage contains a variety of organic and inorganic compounds, part in solution and part in suspension. The organic compounds are of special interest, inasmuch as their concentration is a measure of the strength

of a given sewage. Organic compounds contain primarily carbon, nitrogen, hydrogen and oxygen with small portions of other elements such as phosphorus, chlorine, sulphur, etc. It is very difficult, practically impossible, to isolate definite organic compounds from a substance as complex as sewage, but a satisfactory expression of the amount of organic matter present may be obtained by a determination of various fundamental forms of nitrogen and carbon. The forms of nitrogen which may easily be determined are organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen.

ORGANIC NITROGEN. The organic nitrogen as determined in sewage analysis includes all nitrogen with the exception of that present in ammonia, nitrites and nitrates. The organic nitrogenous matter is present mostly as protein. This is not a definite chemical compound, but a certain class of compounds characterized by the fact that 16 percent of the total substance is nitrogen. The simplest protein is very complicated as compared with the relatively simple composition of such substances as ammonia or mineral salts, the molecular weight of the simplest protein being 5,000, that of water 18 or of sodium nitrate 85.

The bacteria always present in sewage (unless sterilized) break down organic nitrogen into simpler proteins, then into ammonia. This decomposition can be arrested by the addition of sterilizing agents, so that chloroform is usually added to samples of sewage in order to preserve them for analyses. Cold also retards decomposition. Even with this precaution there is some ammonification, so that analyses should be made as soon as possible after collection.

AMMONIA NITROGEN. The formation of ammonia from organic matter is accomplished by bacteria. This decomposition takes place either in the presence or absence of oxygen from the air, and is hastened by warmth up to about 110 deg. Fahr. above which temperature many of the bacteria are killed and the sewage partly sterilized.

The organic nitrogen and ammonia nitrogen, added together, are a fair measure of the organic strength of a sewage. The relative proportions of the two constituents may vary, but the total should not change greatly. For instance, a fresh, cold sewage will have most of its nitrogen in organic form with relatively little ammonia, while an old slowly-moving, warm sewage may have most of its nitrogen as ammonia. The relation of the two forms thus gives an idea of the condition of the sewage under consideration.

NITRITE NITROGEN. In the presence of oxygen and ammonia nitrogen, certain bacteria develop in sewage which have the power of changing ammonia to nitrite nitrogen by oxidation. Considerable oxygen is necessary for the transformation, which usually must be supplied from sources outside the sewage. Quiescent or slowly-flowing sewage cannot absorb oxygen from the air at a rate rapid enough to oxidize the ammonia. For this reason all samples of raw sewage are relatively low in nitrite nitrogen, as compared with organic and ammonia nitrogen.

NITRATE NITROGEN. Although nitrite-forming bacteria are responsible for the first step in the oxidation of ammonia, they are usually found in conjunction with other bacteria which immediately oxidize the nitrite to nitrate nitrogen taking up additional oxygen in the process. These nitrate-forming bacteria are relatively few in raw sewage. In the presence of an abundance of oxygen and partially oxidized organic matter these bacteria develop freely and outgrow the nitrite-formers.

Nitrites and nitrates are rarely found in raw sewage above 1.0 part per million and bear little relation to the strength of the sewage. After a sewage has been well oxidized by biological treatment the nitrite content is usually very low compared with the nitrate.

THE NITROGEN CYCLE. The forms of nitrogen just discussed are interrelated in a cycle of transformation such that the major portion of organic matter eventually is changed to nitrate nitrogen provided plenty of oxygen is present. There is a certain residuum of organic matter which resists the action of the ammonifying bacteria. This organic matter is similar in nature to the humus found in forest soil or cultivated fields. The less resistant nitrogen eventually reaches the nitrate stage, although intermediate products sometimes react to give off free nitrogen gas.

The nitrogen cycle is characteristic of biological changes in nature, and is of fundamental importance in the conservation of nitrogen on the earth. The nitrates present in oxidized sewage are used by plants in the synthesis of the protein of their organic matter. As stated in Marshall's Microbiology, "The plants may be eaten by animals, part of the protein is then digested to urea which in turn is readily decomposed by microorganisms to ammonia. Part of the protein will be stored in the growing animals, and if the animal dies, the body will decay or putrefy, and the nitrogeneous compounds of that body will pass through the various stages of de-

composition to the final products, ammonia. Ammonia is then oxidized to nitrites and nitrates, when the nitrogen cycle is completed." The cycle is more complicated than is indicated by this brief statement, but the general relationships of the fundamental forms of nitrogen are indicated.

OXYGEN CONSUMED. The organic matter of sewage consist almost entirely of protein, carbohydrate, and fats. The amount of protein in sewage may be estimated by the determination of total organic nitrogen. The decomposition products of protein may be followed by determination of ammonia, nitrite and nitrate nitrogen. As yet no simple method has been devised for determining total carbon, the chief constituent of carbohydrate or its decomposition products.

Carbohydrate is the term applied to a general group of compounds containing carbon, hydrogen and oxygen, the proportion of carbon varying, but the hydrogen and oxygen having the atomic relation of 2 to 1. For example glucose is $C_6 H_{12} O_6$, starch $C_6 H_{10} O_5$, etc.

The fats are also hydrocarbons but of a resistant type, which break down very slowly under biological action. The oxygen consumed test for carbonaceous matter includes but little, if any, of the fatty matter. Consequently where fats are an important item, they are determined directly by evaporation of the liquid in a sample, and the extraction of the fat by a solvent, usually ether. In most of the sewage processes the fats break down slowly. In the activated sludge process, however, there is more of a reduction in the fats in the sludge than among other processes.

Although no simple method is available for determining total carbon in sewage, we can gain some idea of the amount of carbonaceous matter present by treating the sample with potassium permanganate under prescribed conditions and determining the amount of permanganate used up. Potassium permanganate is an oxidizing agent containing oxygen readily available which oxidizes the carbon of some carbohydrates to carbon dioxide. The "oxygen consumed" determination on sewage therefore indicates the amount of carbonaceous matter readily oxidizable in a chemical way but does not indicate the total amount. The proportion of the total that is included in this determination is not always the same, some carbon compounds being very resistant to oxidation.

This determination should not be confused with the biochemical oxygen consumption, described later. The "permanganate oxygen consumed" is not a measure of the oxygen required biologically and usually bears no definite relation to it.

SUSPENDED AND DISSOLVED SOLIDS. The suspended solids are those undissolved solids retained on a filter paper or asbestos filter through which a definite quantity of sewage is filtered. The dissolved solids are the solids found in the filtrate and determined by evaporating a sample of the filtrate to dryness in a weighed dish and noting the weight of the residue.

CHLORINE. Chlorine is found in sewage in a soluble form, combined as sodium chloride or common salt. It indicates the strength or dilution of the sewage for the reason that normally most of the chlorine comes from the human urine. Occasionally the chlorine comes from trade wastes such as flow from ice cream factories, packing houses, salt wells, oil refineries, etc. Hence, in packinghouse wastes the chlorine content is very high, but as it is traceable largely to salt used in salting meat and hides it is not an indication of the concentration of organic pollution from human excreta.

ALKALINITY. The alkalinity of sewage is not of much significance, as it varies with the alkalinity of the water supply, plus a small additional amount due to ammonium carbonate and soap. The alkalinity is determined by titration with acid, and represents mostly bicarbonates or carbonates of calcium and magnesium.

BIOCHEMICAL OXYGEN CONSUMPTION. Probably the most important single determination which can be made on a sewage is that of its consumption of dissolved oxygen.

As discussed under nitrogen data the bacteria present in sewage are eager for oxygen and when oxygen is supplied either by aeration or otherwise, they effect the decomposition of nitrogen compounds, changing organic matter to nitrates, and also effect a biological combustion of the carbon, forming carbon dioxide, the final products being mostly of mineral nature. The oxygen required to complete these reactions is known as the biochemical oxygen consumption. Experiment has shown that the oxygen in sodium nitrate is as available for bacterial action as the atmospheric oxygen in solution. By adding to the sewage an excess of sodium nitrate containing a known amount of oxygen, and allowing the bacterial action to ensue, in tightly corked bottles, the biochemical

oxygen demand may be determined. At least 10 days are required at room temperature for the biological reaction to be complete. In this determination, sterilizing reagents are not added to the sample, as they would destroy the bacteria.

The biochemical oxygen demand may be determined in still another way, by diluting the sample with water. Fresh water normally contains a definite amount of atmospheric oxygen for a given temperature, cold water (32 to 40 deg. F.) containing about one and one-half times as much as warm water (70 to 74 deg. F.). If sewage be diluted with pure water, the dissolved oxygen supplied is consumed by the bacteria, thus reducing the oxygen content in proportion to their demand. For example, if a sewage has a biochemical oxygen demand of 200 parts per million and is diluted with water containing dissolved oxygen in the amount of 8 parts per million, 25 volumes of water will be required to supply enough oxygen to meet the demand of the bacteria and organic matter in the sewage.

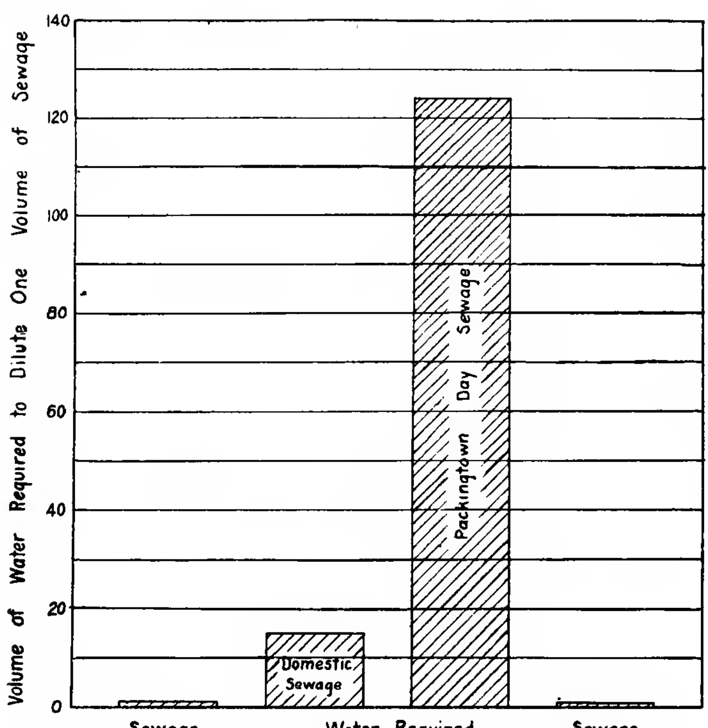



**Fig. 1. Relative Volume of Water Required to Dilute Packinghouse Waste and Domestic Sewage.**

THE STRENGTH OF PACKINGHOUSE WASTE. Based on the analyses as defined, the biochemical oxygen demand of packinghouse waste at the Center Ave. sewer outlet is about 990 parts per million, whereas that of 39th St. sewage is 121 parts per million. In Fig. 1 is shown diagrammatically the relative volume of water containing 8 parts per million dissolved oxygen required to, satisfy these demands.

In 1914, during the operation of the testing station at the 39th St. Pumping Station, 179 determinations of the oxygen demand of the sewage were made on samples taken throughout 24 hours. The flow of sewage per 24 hours on each of these days was measured and the population tributary to the station calculated. These data showed that 0.22 lb. of oxygen were required to oxidize the sewage produced per individual per 24 hours.

In 1917, the flow of all the packinghouses was measured carefully. Determinations made of the average oxygen demand showed that in 24 hours these wastes required 241,190 pounds of oxygen. Assuming that 0.22 lb. of oxygen is equivalent to one individual as stated above, the packinghouse wastes are equivalent to 1,096,000 people. These data were obtained by a thorough and impartial survey. The population equivalent of packinghouse wastes may therefore conservatively be placed at one million.

PROCESSES OF TREATMENT AVAILABLE. In modern sewage practice it is generally possible to purify ordinary sewage to any desired degree. The suspended solids may be entirely removed and the organic matter completely nitrified to produce a clear and sparkling effluent. The bacterial purification may also be made so complete that the effluent is as pure as many a drinking water. Sterilization with chlorine gas or chloride of lime is occasionally necessary. Sedimentation, oxidation and sterilization combined afford a degree of purification very rarely necessary. Sewage treatment should always be carried far enough to avoid local nuisance and the production of conditions offensive to sight and smell. Where sufficient diluting water is available, simple screening may suffice, if the sewage be thoroughly dispersed through properly located outlets. Where diluting water is restricted, the removal of finer suspended solids by tank treatment may be necessary. If but little or no dilution is available, treatment by biological means must be resorted to. The degree of

treatment depends on the digestive capacity of the bodies of water into which the effluent is discharged. The choice of the particular combination of processes best adapted for a given case can only be determined by careful study of local conditions. No set system of sewage disposal exists.

The processes of treatment available for sewage or packing-house waste are varied, including screening, sedimentation in various types of tanks, sedimentation aided by the use of chemicals as precipitants, biological processes and sterilization. Any process requiring a large area is impracticable on this large scale on account of the distance to which this sewage would have to be transported, vacant land within reasonable distance from the stockyards being scarce and high priced.

Processes in general may be divided into several classes according to the degree of treatment. Partial treatment includes the removal of coarse matter by screening, and the removal of grit or sand and the more complete removal of suspended matter by tank treatment, or chemical precipitation. Complete treatment by biological processes would include tanks followed by sprinkling filters or activated sludge for large scale work.

Every practical known process has been studied by the Sanitary District at the Stockyards Testing Station. The "Report on Industrial Wastes from Stockyards and Packingtown", issued in 1914, contains in detail the results obtained up to that time. The results are summarized briefly herein.

## RESULTS OF TESTS THROUGH 1914.

SCREENING. Screening effects only a physical removal of suspended matter of larger size than the openings in the wire mesh or perforated plate used. The openings in the screen tend to clog and must be cleaned frequently by means of a blast of air or steam, a stream of water or mechanical brushing. A rotary screen covered with wire mesh, at first 20, later 30 meshes per inch, was tested over a period of several years. The 20-mesh screen removed about 9 per cent of the suspended matter, the 30-mesh about 19 per cent. No appreciable reduction of the biochemical oxygen demand was effected.

Screens alone are entirely inadequate, but have a definite usefulness, however, preliminary to further treatment by removing

the coarse, floating solids, which are frequently troublesome in tanks or filters.

TANK TREATMENT. Tank treatment comprises many variations of the simple process of allowing sewage to flow through a tank with a velocity sufficiently reduced to allow the suspended solids to sink to the bottom more or less completely. Quiescent sedimentation, in which sewage is run into tanks and allowed to settle without disturbance, might appear feasible but is not generally used on account of the expense.

In continuous sedimentation, the tanks are designed to pass the sewage through at a certain velocity. The length of time of passage through the tank is called the "detention period". The removal of suspended solids is roughly proportional to this detention period. In Fig. 2, the removal of suspended solids is compared with the time of sedimentation under quiescent conditions in order to show that a detention period of several hours is sufficient to remove most of the suspended solids. The conditions of continuous-flow sedimentation do not produce such complete settling of the solids as quiescent sedimentation, for generally eddies or the velocity through the tanks may carry along the finest suspended solids. Fig. 2 also shows the maximum removal of suspended solids possible with packinghouse waste, as well as that possible on domestic sewage at 39th Street pumping Station.

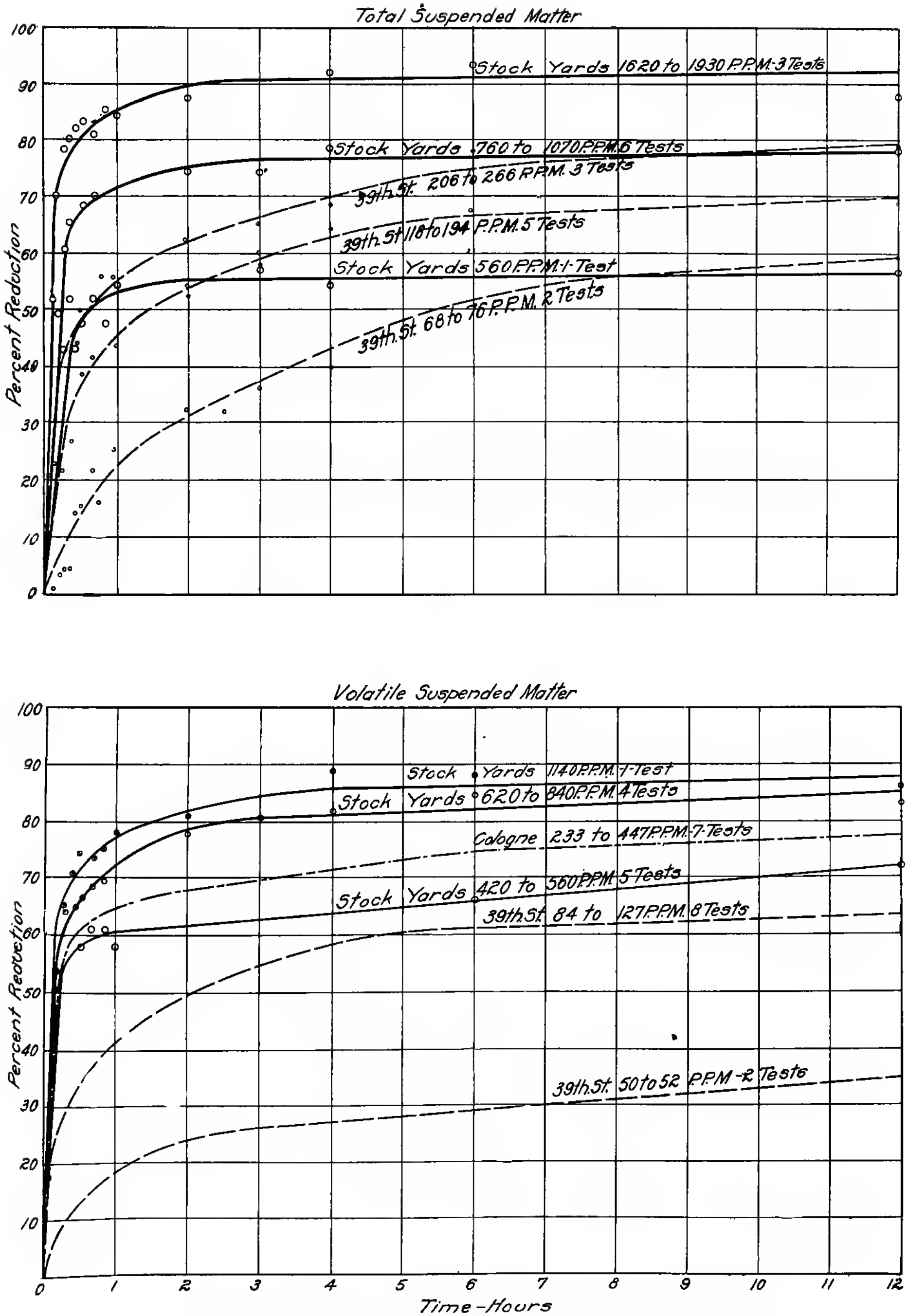
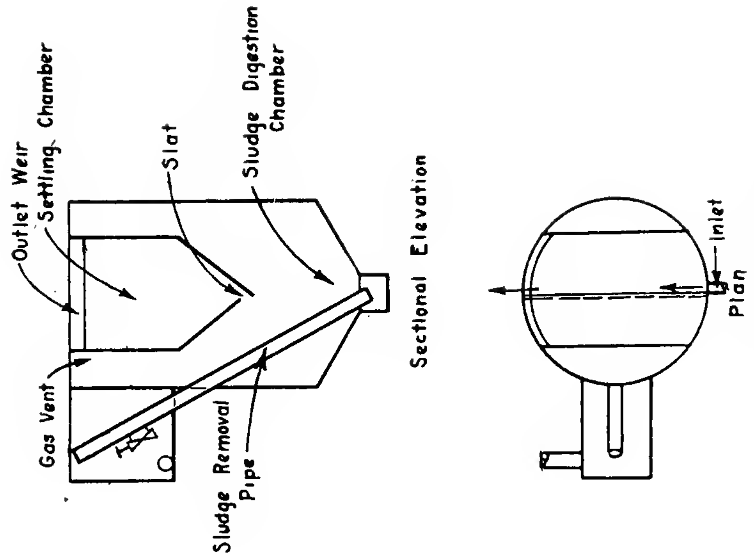
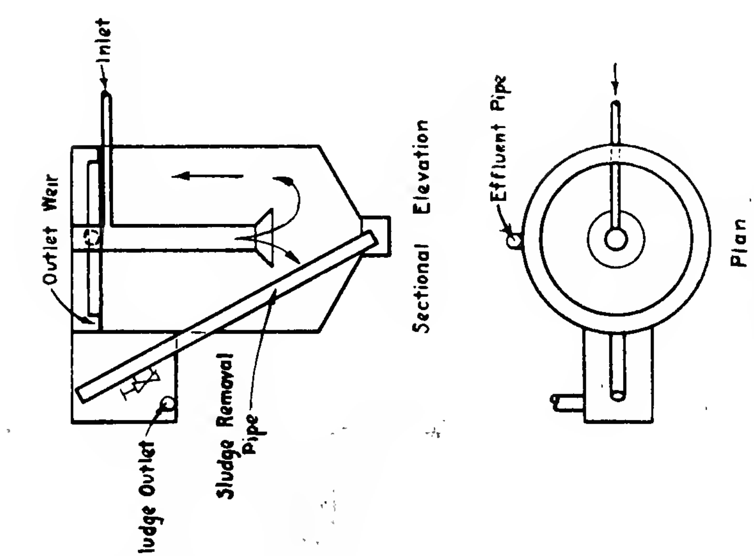



**Fig. 2. Removal of Suspended Matter by Quiescent Settling.**




IMHOFF TANK

Fig. 3.




DORTMUND TANK

Fig. 4.

DORTMUND TANK. Shallow rectangular septic tanks were not considered in the investigation of 1910, as a process of treatment for packinghouse waste. At that time other more efficient settling tanks were used for such sewages. Further the packers had tried septic tanks at Fort Worth many years before without success. The Dortmund tank was considered because

of the ease of removing sludge. Tests were made on two tanks of that type.

The Dortmund tank is known as a vertical flow tank. Such a tank is shown diagrammatically in Fig. 3. The sewage enters at the center of the tank, rising vertically to the effluent trough. The suspended solids fall to the bottom of the cone and form sludge which flows through the sludge pipe, when the sludge valve is opened.

The Dortmund tank removed approximately 55 per cent of the suspended solids and reduced the biochemical oxygen demand 32 per cent and the organic nitrogen 25 per cent. This tank produced a sludge which was difficult to handle. For this reason the use of Dortmund tanks was considered inadvisable.

IMHOFF TANK. An Imhoff tank is a double deck tank of the design shown in Fig. 4. This tank is named after the inventor, Dr. Karl Imhoff, who first placed it in operation at Recklinghausen in 1907 and extended its use in the Emscher district in Germany.

For a period of one to three hours, according to the design, the sewage flows horizontally through the upper compartment. This has steeply sloping bottoms. The suspended solids settle through a slot into the sludge chamber below. The sludge decomposes and gives off bubbles of gas, but in this tank, in contradistinction to single story settling tanks, the gaseous products of decomposition do not disturb the fresh sewage as it flows through the upper compartment, but pass up through separate gas vents. The sludge digests in the tank for several months until it is removed through the sludge pipe by the pressure of the water above it. Typical Imhoff sludge is black and inoffensive and dries readily on sand beds, giving up its water quickly. When dry, it has a brown color and is spongy and light. The condition of the sludge is a result of bacterial secretions called enzymes, which liquefy and gasify the organic matter and leave a sludge entirely different in character from the solids deposited.

The Imhoff tank at the stockyards testing station was operated from 1914 through 1917. The average removal of suspended solids was 65 per cent, the reduction of biochemical oxygen demand 39 per cent, and the reduction of organic nitrogen 26 per cent. The sludge was inoffensive and easily handled. The operation of the Imhoff tank was very satisfactory. In 1914 it was considered the most

promising method for partial treatment of packinghouse waste, preliminary to sprinkling filters.

CHEMICAL PRECIPITATION. The coagulation of sewage by chemicals was one of the earliest forms of sewage treatment and was largely in vogue before 1900. The chemical added reacts with material in solution in the sewage forming a flocculent precipitate which, in settling drags down the finer particles of suspended solids not ordinarily removed by plain sedimentation. Lime, copperas (sulphate of iron) and alum (sulphate of alumina) were used as coagulants. A removal of 70 per cent of suspended solids, 39 per cent organic nitrogen and 38 per cent of biochemical oxygen consumption was obtained by this process. The sludge was ill-smelling and hard to dry. Notwithstanding the fact that the resulting effluent was better than that obtained with the Imhoff tank, chemical precipitation was not considered desirable on account of the large volume of sludge produced and the cost of chemicals.

SPRINKLING FILTERS. Sedimentation only removes the settleable solids, and reduces the oxygen requirements of the liquid between 25 and 40 per cent. From 60 to 75 per cent of the original demand for oxygen or dilution still remains unsatisfied. To effectively treat the liquid so the oxygen demand is reduced to a minimum, dilution and biological treatment are available.

Disposal by dilution will supply the oxygen necessary if enough flow is available. If not available, biological treatment must be resorted to. One of the most effective and intensive forms of biological treatment is the sprinkling filter, consisting of an underdrained bed of crushed stone, usually 1-¼ to 2 inches in size, from 5 to 10 feet deep. The nozzles are spaced so as to spray the liquid uniformly over the surface of the bed. The sewage is broken up into fine drops and absorbs some oxygen from the air. The interstices of the bed are also full of air. The stones of the bed rapidly become coated with films of bacteria which in the presence of air work over the organic matter and produce a humus-like substance, which is gradually washed out of the bed. The nitrite and nitrate-forming bacteria grow vigorously and in conjunction with the plentiful supply of oxygen complete the nitrogen cycle and the reduction of the biochemical oxygen demand. The sewage must not be supplied in too great amount or the nitrate forming bacteria will die and the filter will not accomplish the work for

which it was built. Each sewage acts differently in its effect on these bacteria so that the rate at which it can be sprinkled over the bed must be determined experimentally in unusual cases like the Stockyards. Rates are usually stated in millions of gallons per acre per 24 hours. The rating is fairly well determined for purely domestic sewage.

RELATIVE STABILITY TEST. The nitrate-forming bacteria are very sensitive to changes in the strength of the sewage applied. If a strong sewage is applied too rapidly their activity falls off, the effluent contains less nitrate nitrogen and in some cases no nitrate and no dissolved oxygen. When this occurs it still has a biochemical oxygen demand. In order to distinguish various grades of quality of effluent from a sprinkling filter, a simple test has been devised called the "relative stability test", by means of which the deficiency of oxygen can be ascertained. In this test a sample of the effluent is mixed with a small amount

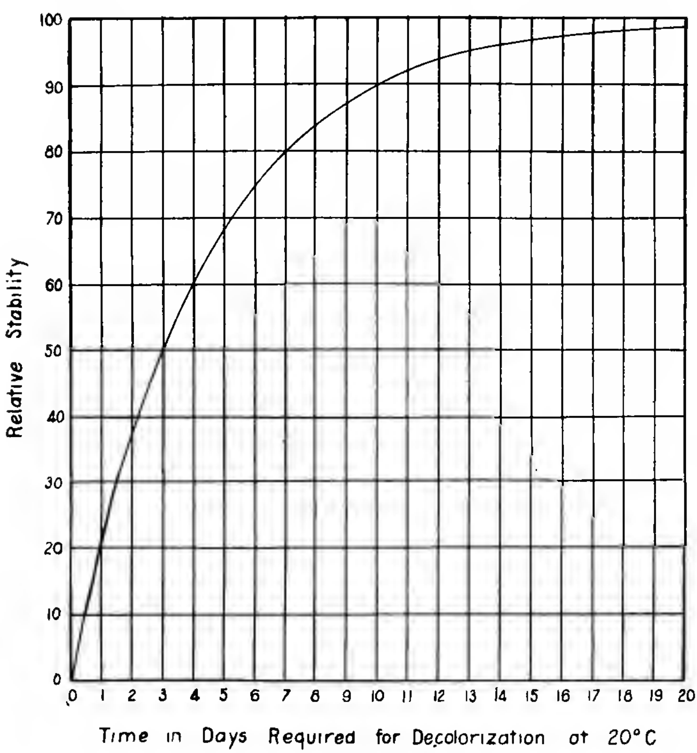



**Fig. 5. Relative Stability Curve.**

of a blue dye, methylene blue, in a completely filled and tightly corked bottle and allowed to stand at room temperature or preferably in an incubator kept at 68 deg. Fahr. This dye has the peculiar property of remaining blue so long as any oxygen is left in the sample either as dissolved oxygen or in nitrites or nitrates, but as soon as all the available oxygen is gone the dye loses its color. Unless the sample is sterile, if the dye remains blue for 20 days, the oxygen demand may be considered to have been met by the oxygen present, and the sample is said to have 100 per cent stability. If the dye loses its color in less than 20 days it is only partially stable. The relation of time in days and per cent stability is shown in Fig. 5. For example, if the sample should remain blue for 4 days it is said to have 60 per cent stability, that is, it contains about 60 per cent of the oxygen necessary to satisfy its biochemical oxygen demand. The relation shown in Fig. 5 may not hold for liquids or effluents other than a sprinkling filter. True relative stability, however, can always be determined by calculation from the ratio of total available oxygen to the biochemical oxygen demand.

Very often it is not necessary to require 100 per cent stability, if the effluent is to be regularly diluted by a few volumes of fresh water containing a sufficient quantity of dissolved oxygen. For conditions existing in Chicago a stability of 85 to 90 or a blue color for 9 or 10 days is considered reasonable, as that time interval means a progress of many miles down the Illinois River.

A sprinkling filter was operated at the testing station for several years, receiving the effluent of the Imhoff tank. It is usual to settle sewage before applying to sprinkling filters in order to prevent clogging of the nozzles and deposit of excessive amounts of suspended matter in the filter. A certain amount of solid matter is delivered to and retained in the filter even with settled sewage. These solids are worked over by the bacteria and low forms of animal life in the filter and discharged with the effluent at irregular intervals. As the suspended matter discharged may be considerable, a secondary settling basin was used following the filter.

The effluent from the filter was excellent, showing good clarification and a relative stability of about 90 per cent. Typical analyses of samples of raw sewage (day), screened sewage, Imhoff tank effluent and sprinkling filter effluent are given herewith.

TYPICAL ANALYSES

Results in Parts per Million

| | Raw Sewage | Screened Sewage | Imhoff Effluent | Filter Effluent |
|---|---|---|---|---|
| Ammonia Nitrogen | 22. | 22. | 29. | 16. |
| Organic Nitrogen | 79. | 75. | 60. | 20. |
| Nitrite Nitrogen | 0.5 | 0.5 | 0.2 | 2.2 |
| Nitrate Nitrogen | 3.0 | 3.0 | 1.7 | 16.4 |
| Oxygen Consumed | 268. | 240. | 180. | 50. |
| Chlorine | 1100. | 1100. | 1100. | 1100. |
| Alkalinity | 212. | 212. | 240. | 200. |
| Suspended Solids | 605. | 515. | 210. | 75. |
| Biochemical Oxygen Consumption | 990. | 930. | 630. | 0. |

The reduction of the biochemical oxygen consumption is of great importance to reduce the load on the main channel. Fig. 6 shows diagrammatically the relative volumes of lake water at 70 deg. Fahr., containing 9 parts per million of dissolved oxygen, required to satisfy this demand before and after treatment by

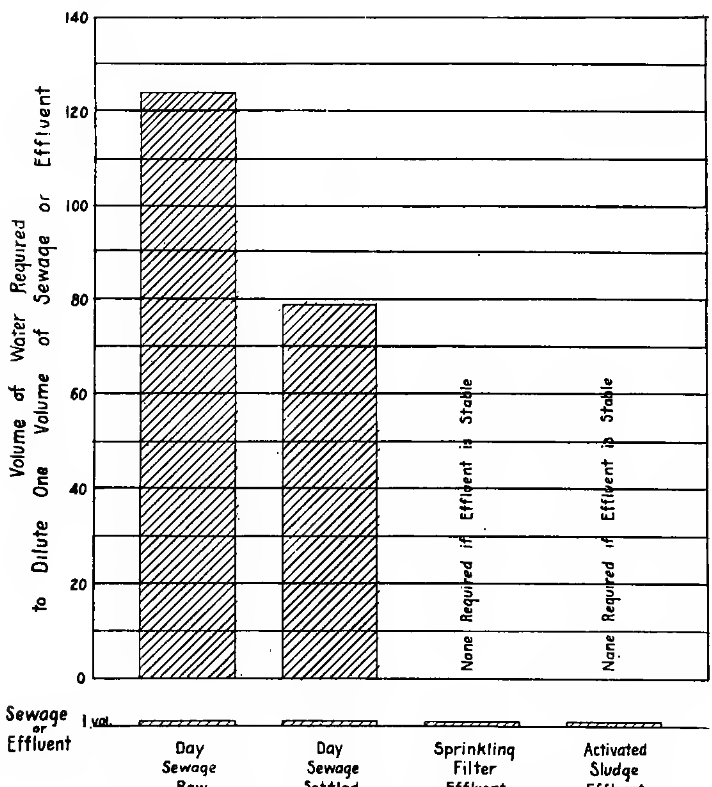



**Fig. 6. Relative Volumes of Water Required to Dilute Various Effluents.**

means of the three processes listed. This diagram shows the remarkable improvement in the character of the waste effected by complete treatment. The difference between the volume of water required to meet the demand of the total untreated wastes (241,200 lbs. oxygen per 24 hr.) and that of a 100 per cent stable effluent (0 lb. per 24 hr.) amounts to three billion two hundred sixteen million (3,216,000,000) gallons of water per day, about four and one-half times as much as is pumped for the water supply of Chicago.

CONCLUSIONS, 1914. At the end of the experimental work in 1914, the most feasible solution of the problem of treating packinghouse waste appeared to be treatment in Imhoff tanks in a plant to be built in the bed of the West arm of the south fork of the south branch of the Chicago River, west of Ashland Avenue. Further treatment by sprinkling filters was suggested. The area required for sprinkling filters could not be obtained near the Yards, but was available about three miles to the west.

## ACTIVATED SLUDGE.

DISCOVERY OF ACTIVATED SLUDGE PROCESS. In the early nineties, considerable attention was given to the possible oxidation of sewage by forced aeration. The early experiments of English and American investigators showed that with use of air alone, in reasonable periods of contact, but little improvement was obtained. The methods of chemical procedure then available to determine the changes in the liquid were not as delicate or satisfactory as now. Consequently interest in aeration lapsed for nearly 20 years. In 1911, aeration experiments were begun upon improved lines at Brooklyn, N. Y., treating settled sewage. The results were encouraging. Following this, various studies were made at the Lawrence Experiment Station of the Massachusetts State Board of Health on aeration in connection with various methods of sewage treatment. This work was visited by Prof. G. J. Fowler (Professor of Chemistry, University of Manchester, Manchester, England), in 1913, who derived therefrom the inspiration which led to the announcement in November, 1913, that Fowler and Mumford had inoculated sewage with oxidizing bacteria and had thoroughly clarified and rendered non-putrefactive the sewage by six hours of aeration.

DEVELOPMENT OF ACTIVATED SLUDGE. In the spring of 1914, as a result of the work of Fowler and Mumford,

a further departure in the treatment of sewage by aeration was reported by Ardern and Lockett, working under the direction of Prof. Fowler. Their first experiments were made in gallon bottles and consisted in blowing air into sewage continuously for several weeks until all the ammonia nitrogen was converted into nitrate nitrogen. The air was then turned off, the suspended solids allowed to settle, and the supernatant liquid poured off. Fresh sewage was next added. The aeration was again resumed. This time the nitrification took place in about one week. In about two months, by successive additions of sewage and retention of the solids, sludge was accumulated to occupy about 25 per cent of the volume of the aerated mixture. Complete nitrification was then accomplished in from 4 to 6 hours. The acceleration in nitrification proved to be due to the accumulated sludge, which was so different from any sludge previously obtained from sewage that it was given the name "activated sludge".

This sludge contained large numbers of nitrite and nitrate forming bacteria. In its action it behaved like the slimy films found on the stones of ripened sprinkling filters. The activated sludge, however, contained more nitrogen than the sprinkling filter sludge. The effluent from the activated sludge process proved much clearer than the effluent from sprinkling filters.

Following this, experiments were carried on in England, and at various points in the U. S. The development was accelerated by the work done at Brooklyn, Chicago, Baltimore, Urbana, and in particular at Milwaukee. The "fill and draw" method of operation proved uneconomical, so all large-scale experiments were made on a "continuous flow" basis, in which the sewage continuously flows through the aeration tanks, to a settling tank, in which the activated sludge is removed and returned to the aeration tanks for the treatment of fresh volumes of incoming sewage. A diagrammatic sketch of the operation of a simple continuous flow activated sludge plant is shown in Fig. 7.

Approximately 25 per cent of sludge by volume must be maintained in the aerating tanks. When the sludge accumulates over this amount the excess is removed for disposal. Early analyses of this sludge showed high nitrogen content compared with other sewage sludges, thereby making it of greater value as a fertilizer, when dried. This process is not as yet self-supporting. However, it has been hoped that the sale of the sludge would more than cover the cost of sludge handling.

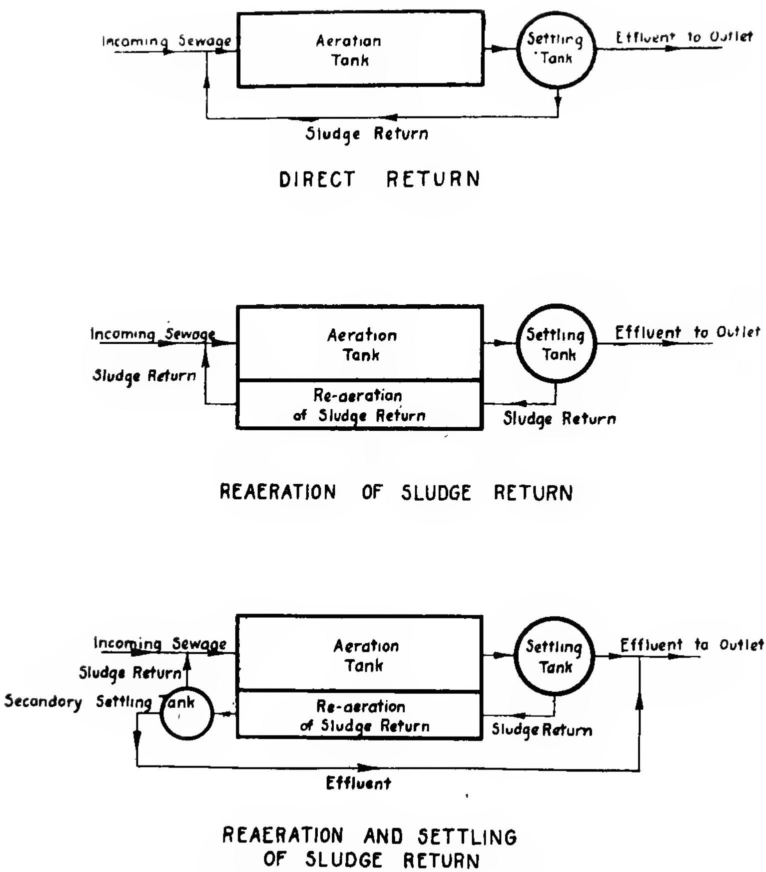



**Fig. 7. Schemes of Flow in Activated Sludge Plants.**

The testing work has shown the correctness of the process in producing results, but has also demonstrated markedly the difficulties in handling the sludge. This is partly a physical and partly a mechanical problem. Activated sludge, as removed from the tanks, is very dilute, usually containing from 98 to 99.5 per cent of water. The individual particles are so fine that they retain the water content tenaciously and release it but slowly. Up to the present time, the usual treatment has been filter pressing. The cost of filter pressing is large. The problem resolves largely into finding the best way of conditioning the sludge by aeration, adding acid, settling, or otherwise, so that it will release the water more readily in a press. The press cake contains 75 to 80 per cent moisture. This can be dried and put in shape for sale as fertilizer.

The object of the activated sludge tests has been to define the engineering conditions required, the amount of air both per gallon of sewage and per square foot of tank surface; the most economical depth of tank, the method of settling, the method of operation; the capacity of filter presses; effect of screening, and other data. The desire is to reduce the amount of air and consequently the amount of power required, and further cut the cost of sludge handling.

DEFINITION OF ACTIVATED SLUDGE. "The activated sludge treatment may be defined as a biochemical process by which the purification of the sewage is accomplished by passing it through tanks, in which sewage sludge is artificially agitated and intimately mixed with sewage and is supplied with the requisite oxygen for the optimum development of countless numbers of nitrifying organisms incorporated in and adhering to the sludge, the final settlement of which causes a distinct clarification of the oxidized sewage.

The activated sludge itself is a flocculent sludge, accumulated in the presence of air, of medium brown color, which contains masses of aerobic organisms which have acquired the power of rapidly oxidizing and nitrifying the sewage. The sludge is added to the incoming sewage, kept in contact with aeration for a number of hours, and then settled out. The liquid passing off is very clear. According to the extent of the treatment, any reasonable degree of purification may be obtained."

The extended experiments made at Milwaukee and at Chicago have shown that an activated sludge plant should contain screens to remove coarse material, a grit chamber to remove sand or heavy material, aeration tanks in which the sludge and sewage are kept thoroughly mixed by the use of air diffused through porous plates and settling tanks in which the sludge is removed from the liquid and sent back to meet the incoming sewage.

At the present time three methods are available for operating such a plant (Fig.7). In one, the sewage and sludge are aerated together, the sludge settled and returned to meet the incoming sewage. In a second, the sewage and sludge are aerated together, the sludge settled and re-aerated during its return to meet the incoming sewage. In a third, the sewage and sludge are aerated together, the sludge settled and re-aerated, and the re-aerated sludge resettled before return to the incoming sewage.

TESTS AT STOCKYARDS, CHICAGO. The experiments, begun at the Stockyards in 1915, and continued until 1918, included a preliminary investigation in small galvanized iron tanks followed by large-scale experiments in wooden tanks. A summary of the results obtained follows.

## CHICAGO TESTS, 1915 TO 1918.

PRELIMINARY TESTS. Preliminary tests on a fill-and-draw plan demonstrated the feasibility ot activated sludge treatment. Approximately 3.0 cu. ft. of free air (i. e. measured at atmospheric pressure) were required per gallon of sewage and a contact period of at least 8 hours, to obtain stability. From one-half to one hour quiescent settling sufficed.

LARGE SCALE TESTS. The first set of large scale experiments were made on a continuous flow basis. The sludge was returned directly from the settling tank to the aeration tanks. During the warmer weather, a stability of over 50 could be secured with about 9 hours aeration and 3.5 cubic feet of air per gallon of sewage. In the colder weather lower stabilities (10 to 38) were secured with about 9 hours aeration and 4 to 5 cubic feet of air per gallon of sewage.

The second set of experiments were made on a continuous flow basis, but the sludge was re-aerated and resettled after removal from the settling tank, before being returned to be mixed with incoming sewage. This re-aeration and resettling was expected to result in a saving in tank space. Inasmuch as the sludge return frequently exceeded 25 per cent of the total mixture in the aerating tanks, separate aeration of the sludge was looked to for reducing the volume of sludge and the period of contact. By resettling the sludge after re-aeration, it was found that a considerable amount of purified liquor could be removed, and a more concentrated sludge returned to the aerating tanks.

The average aeration periods were around 5.3 hours in the sewage tanks and 3.8 hours in the re-aeration tank, the weighted average being equivalent to a 6.6 hour period. This is seen to be shorter than 9 hour aeration required without re-aeration, resulting in a substantial saving in tank space. On the other hand more settling space is required with re-aeration, the settling period being 1.3 hours with aeration and 1.7 hours with re-aeration. The air consumption is about the same in either case, 3.5 cu. ft. per gallon

of sewage. The stabilities ranged from 38 to 95 per cent. Although re-aeration effects a substantial saving in tank space, it increases the complexity of the process and necessities more careful supervision of the plant. For these reasons it is still doubtful whether re-aeration and resettling are desirable in a practical, working plant.

The third set of experiments were made under winter conditions on a continuous flow basis, but without re-aeration of the sludge, before return to the aeration tank. An average of 4.3 cubic feet of air per gallon of sewage was used with an aeration period of 8 hours. The stabilities ranged from 41 to 71 per cent.

The quality of the effluent produced by activated sludge treatment was considered reasonable, and the amount of air and tank space required were not excessive, in view of the strength of the waste. Milwaukee results indicate that 4 to 5 hours aeration, with 1.5 cu. ft. of air per gallon, are required for the sewage of that city, which is about 1/3 the strength of packinghouse waste.

It was found desirable to screen the sewage through a 20 or 30 inch screen before aeration in order to remove much comparatively inert coarse material which resists oxidation and might settle on the bottom of the tank unless an excessive amount of air be used to keep it in suspension. Inasmuch as this material contained only about 80 per cent moisture, it would not require filter pressure, thereby making a saving in operating cost.

REMOVAL AND DISPOSAL OF ACTIVATED SLUDGE. After the sludge in the aerating tanks reached 25 per cent by volume, a varying amount was removed each day, corresponding roughly to the quantity of solids brought into the tanks by the incoming sewage. About 2300 lb. of dry sludge were obtained from each million gallons of waste. As the sludge removed from the tanks contained 99 per cent water, this necessitates the removal of about 28,000 gallons of wet sludge per million gallons. With a total flow of packinghouse waste around 58,000,000 gallons per 24 hours, about 162,400 gallons of wet sludge would have to be disposed of every day. To handle the sludge commercially, the water must be extracted. This is done by pressing, followed by drying in rotating hot air dryers. Experiments made with a small filter press, in which the sludge was filtered out on cloth, showed that the water content of the sludge could be reduced from 99 to 75 per cent by pressing for 3½ hours with an ultimate pressure of 125 pounds. The addition of 2 cubic centimeters of sulphuric acid

per gallon of sludge practically cut the time of pressing in half, acidification thus reducing the number of presses required by one-half. The Milwaukee tests have shown that activated sludge can be dried in rotary dryers after filter pressing. No tests were made of dryers at Chicago. The sludge after drying contains from 4.0 to 5.0 per cent nitrogen and from 5.0 to 7.0 per cent fats. The sludge has value as a fertilizer and should be recovered for sale.

LENGTH OF TESTS. Since the publication of the 1914 report the investigation of the individual houses has continued and has been brought up to date. Further, in 1915, experiments were undertaken on the activated sludge process. The preliminary results, obtained on a very small scale were so encouraging that in October the construction of a larger scale plant was begun. This was put into service on January 10, 1916. From time to time the plant was changed to study the variations to be made by different methods of construction and operation, with the results given herein. The plant was kept in operation with considerable difficulty during 1918, owing to the war, and was finally dismantled upon completion of the experiments in September of that year.

NEGOTIATIONS FOLLOWING TESTS. Based on the results available in 1916, a preliminary statement was made by W. D. Richardson, representing the packers, and Langdon Pearse, representing the Sanitary District, in which both agreed that the activated sludge process was the most likely to prove successful in handling the industrial waste from Packingtown. This was followed in April, 1917, by a report in which a scheme for the collection of the sewage and its treatment was worked out at considerable length in a preliminary way with estimates of cost. This was supplemented in 1917 by a comprehensive survey of the existing houses to determine their flow and amount of pollution, on which a report was made by the Chief Engineer in November, 1917, giving the relative liability of the packers (Appendix 2). The cost of this survey was paid by the packers. The survey also showed that the normal capacity of the plant should be taken at 58 million gallon per 24 hours, instead of 48 million, as on the 1916 report.

During the war, negotiations were at a standstill. In 1919, however, the matter of adjustment of costs and procedure was taken up with vigor and pushed. The attendance of representatives of municipal organizations was invited at the conference of the trustees and representatives of the packers. As a result of negotia-

tion, the packers have offered to pay sixty per cent of the cost of treatment and also of the net operating cost, if the District will assume the remaining forty per cent. A suggested form of contract has been drafted and is now under consideration.

SITE. The Sanitary District has available the right to use 7.8 acres at the forks of the east and west arms of the south fork of the south branch of the Chicago River on property owned by the Union Stockyards and Transit Company. For the construction of the plant, however, more acreage is desirable in order to keep down the cost of operation which deep tanks would necessitate and to have some available area for future development. An alternate site has been discussed just south of 38th street and east of Ashland Avenue. This would permit the filling of the west arm from the north side of west 39th street to the east side of Ashland Avenue. The legal complications attendant to acquiring this site are being worked out. It is possible that a third site may be found which is more attractive. For the purposes of treatment it has been considered desirable, both from the financial and sanitary standpoint, to have a site close to the source of the waste in order to avoid the decomposition and nuisance which might accrue, if the liquid was carried throughout a long interceptor.

## TECHNICAL SUMMARY.

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MAGNITUDE OF PROBLEM. In order to show the magnitude of the problem, and its growth, particularly during the war, figures furnished by the Drovers' Journal have been compiled, giving the statistics of the head of cattle, hogs, sheep and calves killed in the City, from the beginning of the Stockyards in 1866 to date (Fig. 8). For the period from 1910 to date, the total weight of the animals killed has been estimated. The total weight is a far more accurate index than the number of animals killed, owing to the vast difference in the weight of the various animals.

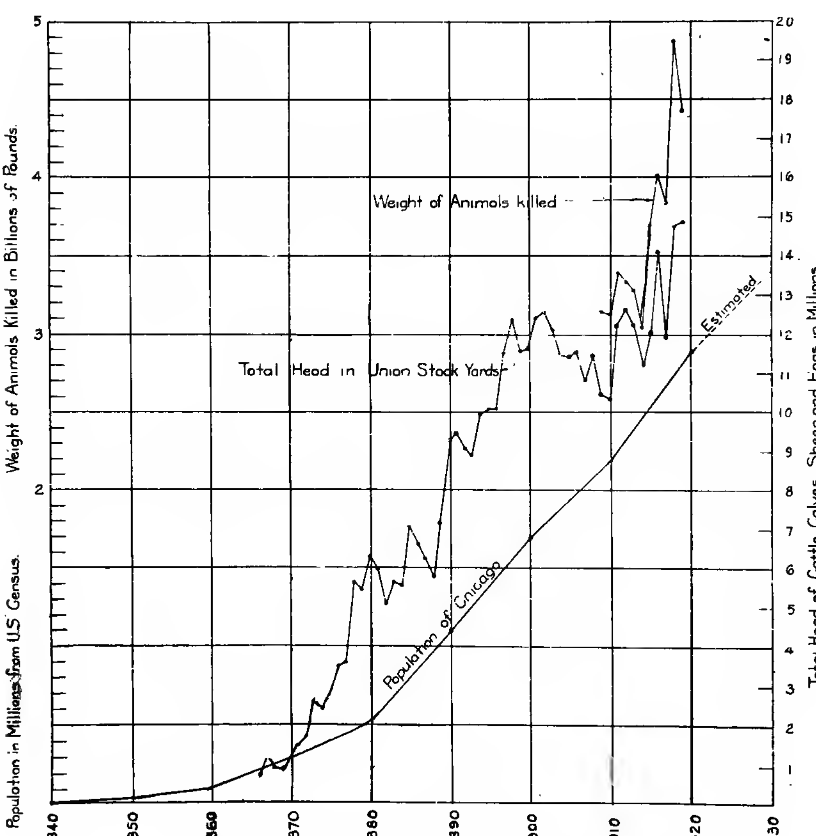


**Fig. 8. Total Head Slaughtered and Population.**

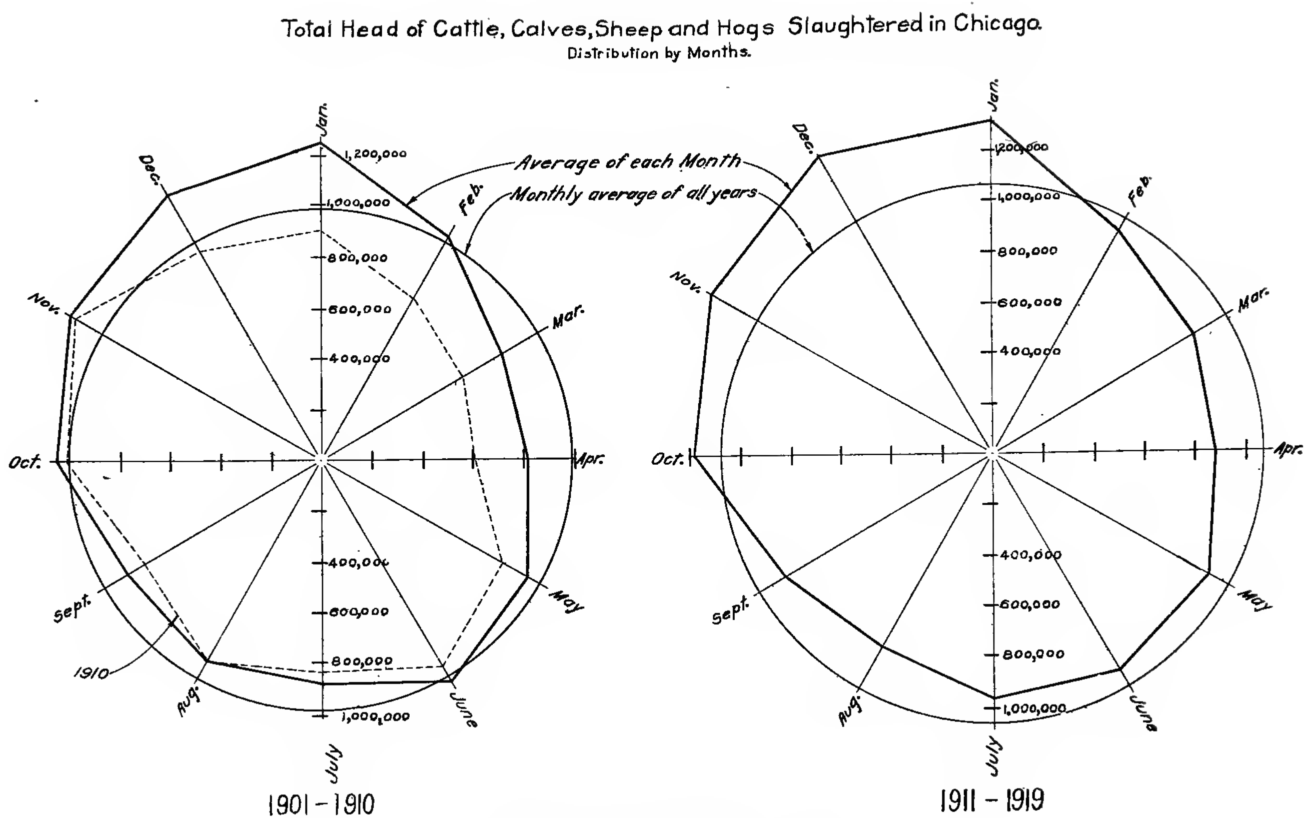


**Fig. 9. Seasonal Variation of Kill.**

The increase in killing of cattle during the war pushed up the total weight markedly in 1915 and 1916 to a greater extent than the increase in numbers would indicate. At the time the report of 1914 was published the curves showed a decrease in Packingtown since 1900, due to the increasing number of Western packing centers at Kansas City, St. Joseph, Omaha, Fort Worth, etc., but with the increased demand for food products due to the European war, slaughtering in Chicago jumped from 10,300,000 head in 1910 to over 14,000,000 in 1916. The packers held the opinion in 1914, that the peak of the business growth in Chicago had been reached, but the effect of the war upset all prophecies. In 1918 and 1919, the total killing again exceeded all past figures in total weight, if not in numbers.

SEASONABLE DISTRIBUTION. From the standpoint of the operation of the main channel of the Sanitary District, and the load of organic matter to be cared for, it is important that the seasonable distribution of the kill be known. The total head slaughtered has been averaged by months for the period from 1901 to 1910 and from 1911 to 1919 inclusive (Fig. 9). The results show a slightly heavier load in the autum and early winter than in the spring and summer months. A comparison of the diagram for the two periods indicates practically the same seasonal distribution, the winter killing being somewhat greater in the period 1911-1919.

THE PACKING INDUSTRY. The processes involved in the houses in Chicago are still carried along substantially as indicated in the report of 1914. Since then, however, considerable attention has been given in the operation of the larger houses to the retention of grease and to the evaporation of tank water to a greater extent than before. Even the smaller houses have done likewise. In addition, Swift & Co., Wilson & Co., and Boyd, Lunham & Co., have installed fine screens on the outlet of the paunch manure presses.

EXPERIMENTS BY PACKERS. In addition to the tests described herein made by The Sanitary District of Chicago, some experiments were made privately by the packers on different sewer outlets. The results obtained by Armour & Company, so far as they have been made public, are detailed in an article by Rudnick and Noble in the Journal of Industrial and Engineering Chemistry (Vol. 8, pp. 651-2). Swift & Company also built an activated sludge plant of considerable size on the outlet to the Ashland Avenue sewer. Owing to the war it was not completed for many months,

and when operated was utilized largely to determine whether or not the sludge produced could be filter pressed. This plant included a screen of the Jennings type, aeration tanks and a sludge press of the plate type. Wilson & Company also made some tests on activated sludge and further tried out the use of the electrolytic plant of the Landreth type, using lime in connection with the passage of electrical current between iron plates. The general purpose of these experiments was more to determine the character of the material recovered than to establish the degree of purification in an effluent. Consequently, the lime-electrolytic process was abandoned because of the great amount of lime in the recovered material. So far as can be ascertained the results obtained by the packers on activated sludge were encouraging, and served a purpose in leading them to agree that the activated sludge process was the most practicable process for handling the sewage of Packingtown.

CRUDE SEWAGE. The crude sewage is strong compared with a domestic sewage. It was strongest in 1917. For the day sewage, the suspended solids range from 281 to 506 p. p. m. on monthly averages, the oxygen consumed from 150 to 269 p. p. m., the fats from 80 to 191 p. p. m. and the biochemical oxygen consumption from 834 to 1477 p. p. m. For the night sewage, the suspended solids range from 73 to 313 p. p. m. on monthly averages, and the fats from 12 to 134 p. p. m. Most of the nitrogen present is in organic form, the ammonia nitrogen being very low.

The temperature of the crude sewage is higher than in domestic sewage, the effluent averaging 55 to 60 deg. F. in the winter months.

PRELIMINARY TESTS ON ACTIVATED SLUDGE. FILL AND DRAW. Preliminary fill and draw tests on tanks holding from 190 to 210 gal. demonstrated the feasibility of activated sludge treatment. Approximately 3 cu. ft. of free air were required per gallon of sewage and a contact period of at least 8 hours, to obtain a fair stability. From ½ to 1 hour quiescent settling sufficed.

## OPERATION OF ACTIVATED SLUDGE. CONTINUOUS FLOW.

First Period. Continuous Flow. Without Re-aeration.
July 1, 1916 to March 26, 1917. 15 runs.

From July 1 to October 22, effluents were secured with a relative stability of 52 to 90 on the run averages. The periods of aeration ranged from 8.9 to 13.2 hr., with settling periods of 1.6 to 2.7 hr. The air used was from 3.27 to 4.41 cu. ft. of free air per gal. with a distribution from 0.25 to 0.31 cu. ft. per sq. ft. on run averages. The highest stabilities occured with the longest aeration period, the lowest with the shortest. The results showed, however, that during the warmer weather an effluent with a stability of over 50 could be secured with about 9 hr. aeration and 3.5 cu. ft. of air per gal. of sewage, corresponding to a rate of 0.34 cu. ft. per sq. ft. per min.

From Oct. 23, 1916, to March 26, 1917, effluents were secured with a relative stability of 10 to 38, on the run averages. The period of aeration ranged from 6.9 to 10.9 hr. with settling periods of 1.1 to 2.2 hr. The air used was from 3.17 to 6.52 cu. ft. of free air per gal. with a distribution from 0.24 to 0.59 cu. ft, per min. per sq. ft. on run averages. The results showed, however, that during the colder weather an effluent with a stability from 10 to 38 could be secured with about 9 hr. aeration and 4 to 5 cu. ft. of free air per gal. of sewage. The increase of air to 6.5 cu. ft. per gal. did not produce a stability higher than 27.

NUMBER OF UNITS. When four aeration units were operating, the stabilities taken from the effluents at the outlet of the second and third (table 41 and 42) indicate that the function of the last unit is largely to condition the sludge.

## OPERATION OF ACTIVATED SLUDGE.

Second Period. Continuous Flow Re-aeration.
March 27 to November 14, 1917. 10 Runs.

During this period the sludge was re-aerated and settled, before return to the aeration tank. Air was applied uniformly throughout 24 hours but increased daily from Monday to Saturday. Re-aeration of the sludge effected a large reduction in volume of sludge returned. More sewage was treated in three aera-

tion tanks than previously in four. Average aeration periods were around 5.3 hr. in the sewage tanks, and 3.8 hr. in the sludge re-aeration tank, the weighted average being equivalent to a 6.6 hr. period. The average settling period was 1.8 hr. in the primary, 1.6 hr. in the resettling tank, the weighted average being equivalent to a 1.7 hr. period. The air consumption was approximately 2.5 cu. ft. per gal. of sewage and 2.9 cu. ft. per gal. of re-aerated effluent, a weighted total of 3.5 cu. ft. per gal. of sewage treated. The stabilities obtained, however, were low from the main settling tank running from 32 to 94, and somewhat higher from the re-settling tank running from 38 to 97, the averages for the combined effluent running from 38 to 95. The results on the day flow are lower.

## OPERATION OF ACTIVATED SLUDGE.

Third Period. Continuous Flow. Without Re-aeration.
November 16, 1917, to February 12, 1918. 4 Runs.

During this period, the sludge was returned directly from the main settling tank, without re-aeration or resettling. An average of 4.3 cu. ft. of air per gal. of sewage was used, with an aeration period of 8 hours. The settling period was 0.97 hr. in the inclined tank. The stabilities averaged from 41 to 71 percent.

SLUDGE RATIO. The sludge ratio in the aeration tanks is commonly determined volumetrically. The ratio thus depends on the quality and moisture content of the sludge. The amount of returned sludge varied with the moisture content. The sludge return on run averages, ranged from 48 to 79 percent, being lowest in the warmer months. The normal was about 60 percent. An average of 30 percent seems to be required for the sludge percent in the tanks. This varied from 19 to 48 percent. In winter, a somewhat higher percent is required than in summer. But for clarification only, the amount may be reduced, averaging from 20 to 28 percent.

RESULTS, SUMMER AND WINTER. In the warm weather, the organic nitrogen is well reduced. The ammonia nitrogen is reduced in lessening amount as the weather cools. The nitrate formation was strong. In cold weather the organic nitrogen was reduced, but in slightly lower amount. The ammonia nitrogen increased markedly, as opposed to a decrease in warm weather. The nitrate formation was markedly decreased.

COMPARISON. AERATION VS. RE-AERATION. Comparison of summer results indicates a saving of approximately 27 percent of aeration tank volume with re-aeration and resettling of the sludge. But 31 percent more settling tank capacity is required. Consequently a net saving of 20 percent of tank volume seems probable. A slight saving in air consumption, approximately 10 percent, also appears possible with re-aeration.

| | Period in hours | | Air Cu. Ft. per Gal. | Ratio** | Period Compared |
|---|---|---|---|---|---|
| | Aeration | Settling | | | |
| Aeration | 9.0 | 1.3 | 4.0 | 0.60 | Jan. 2 to Oct. 22–16 |
| Re-aeration* | 6.6 | 1.7 | 3.5 | 0.39 | Mar. 27 to Nov. 14–17 |

*Re-aeration with resettling.
**Ratio sludge return to sewage.

The effluents produced are fairly comparable, though the "aeration" effluent is in general somewhat better.

SETTLING AND CONCENTRATING ACTIVATED SLUDGE. The rate of subsidence depends on the state of activation, physical appearance, moisture content and temperature. In general but little additional concentration was gained by settling more than 2 hours. The concentration occured much faster in the shallower tank.

The position of the settling vessel also had an influence in cylinder and can experiments, probably in large part because of the increase in effective settling area. Inclinations of less than 45 deg. with the horizontal were not effective.

This principle can be utilized, if desirable, in settling tank construction on a small scale. The results indicate a rate of settling for a 60 deg. inclination of 950 to 1400 gal. per sq. ft. tank area per 24 hr., compared with the Dortmund type, horizontal flow type or combined vertical and horizontal flow type of 500 to 650 gal. per sq. ft. per 24 hr.

SLUDGE. Typical activated sludge from Packingtown is brown in color, settling quickly, and leaving a distinct line of demarcation. The moisture content in the aeration tanks, after 1 hour settling, and in the settling tanks practically runs over 99 percent water.

Typical analyses are as follows:—

| Sludge | Sp. Gr. | Percent. Moist. | Calculated to Dry Weight Percent. | | | |
|---|---|---|---|---|---|---|
| | | | Nitrogen | Volatile | Fixed | Ether Sol. |
| Activated | 1.004 | 99.15 | 4.17 | 62.6 | 37.4 | 6.0 |
| Imhoff | 1.02 | 91.5 | 2.72 | 65. | 35. | 6.6 |
| DORTMUND TANKS | | | | | | |
| Tank D | 1.02 | 91.7 | 2.88 | 76. | 24. | 8.6 |
| Tank C | 1.02 | 90.6 | 2.65 | 72. | 28. | 8.1 |
| Acid Treatment | 1.02 | 92.5 | 3.07 | 74. | 26. | 18.8 |

These typical analyses show that activated sludge is more liquid, higher in nitrogen and lower in fat, on Packingtown sewage, than other sludges.

RELATION OF SLUDGE TO SUSPENDED MATTER. In determining the dry weight of the sludge, special precautions were taken to eliminate error from solids in solution.

The results in the various periods may be summarized as follows:—

| Period | Per Million Gallons | | |
|---|---|---|---|
| | Pounds Removed Dry Basis Sludge | Pounds Removed Dry Basis Suspended Matter | Sludge Percentage Suspended Matter |
| 1916, Sept. 17 to 1917, Mar. 26 | 2680 | 2820 | 95 |
| 1917, Mar. 27 to Nov. 14 | 1924 | 2280 | 84 |

NITROGEN RECOVERY. The nitrogen balance is approximately summarized as follows for two periods given:—

| | Total Input Influent | Changed To | | | | |
|---|---|---|---|---|---|---|
| | | Amm. N. | Org. N. | Nitrite Nitrate N. | Gas | Sludge |
| | Period August 1, 1916, to March 26, 1917 | | | | | |
| Summer Lb. per Mg. | 469 | 83 | 61 | 42 | 193 | 90 |
| Percent. Total | 100 | 18 | 13 | 9 | 41 | 19 |
| Winter Lb. per Mg. | 592 | 209 | 113 | 2 | 138 | 130 |
| Percent. Total | 100 | 36 | 19 | 0 | 23 | 22 |
| | Period March 27, 1917 to November 14, 1917 | | | | | |
| Lb. per Mg. | 380 | 84 | 52 | 25 | 134 | 85 |
| Percent. Total | 100 | 22 | 14 | 7 | 35 | 22 |

The results indicate a higher recovery of nitrogen in the sludge during the winter. The recovery is somewhat greater with re-aeration (March 27 to November 14, 1917.)

DEWATERING SLUDGE. The experiments tried at the Stockyards Testing Station included air drying on sand beds, lagooning, concentration, and filter pressing.

AIR DRYING. On prepared sand beds, activated sludge dried much more slowly than Imhoff sludge.

LAGOONING. Lagooning was unsuccessful. The sludge settled to the bottom, the water remained at top. Concentration was effected only by evaporation. Considerable odor developed.

FILTER PRESSING. Sludge was pressed successfully without the use of lime in a standard type of plate press.

Tests were made with a plate press of the center feed type, containing 12 corrugated plates, each of 225 sq. in. filtering area, having eleven chambers. The sludge was fed by an ejector. For the best results, the air pressure was built up in lb. per sq. in. as follows:—

At start, 15; at ½ hr., 60; at 1 hr., 100; at 2 hr., 140.

The time of pressing varied from 2 to 5 hours, but was materially shortened by providing a sludge well activated, with the characteristic physical appearance.

The first 20 tests were made with a ⅞ in. cake. Radial ribs were then added, which improved the hardness of the cake. Thicker cakes were tried from 1 to 1⅜ in. The thicker cakes were less firm, the thickest being the softest.

| Thickness of Cake Inches | Moisture Percent. | Wet Cake | Dry Cake | Pounds Water to be Evaporated to Produce Ton Dry Cake |
|---|---|---|---|---|
| ⅞ | 73.9 | 80. | 20.9 | 5670 |
| 1 | 76.3 | 91.5 | 21.7 | 6430 |
| 1⅛ | 77.6 | 103. | 23.1 | 6930 |
| 2¼ | 78.3 | 114. | 24.7 | 7220 |
| 1⅜ | 78.2 | 126. | 27.4 | 7180 |

The use of acid (sulphuric acid or acid cake) in amount sufficient to neutralize the alkalinity of the sludge, improves the yield of cake, prevents decomposition of the sludge, reduces clogging of filter cloths, increases the nitrogen and fat content of the sludge.

The sludge before pressing ranged from 97.9 percent moisture upward. The cake varied in moisture content, from 78.5 to 89 percent, without the radial ribs, and from 74.2 to 80.6 with the ribs. The more concentrated the sludge (within the limits investigated) the shorter the time of pressing and the better the results.

The time of pressing has an influence on the moisture content.

| Pressing Net Time Hours | Pounds of Cake | Moisture Percent. | Cake Dry Pound | Condition of Cake | Estimated Press Cycle Hours |
|---|---|---|---|---|---|
| 3.5 | 81. | 75.9 | 19.5 | Very Good | 4. |
| 3.0 | 80 | 79.1 | 17.5 | Good | 3.5 |
| 2.5 | 79 | 80.6 | 15.3 | Fair | 3. |

Acidification increased the yield of a pressing in one case 38.5 percent, and in another 11.7 percent, but in the latter case a drier sludge was produced in half the time required for non-acidified sludge. The same result was noted with dye-works acid waste or with nitre cake, used in place of sulphuric acid.

Sludge analyses made during the press tests showed a higher proportion of organic nitrogen than the sludge previously noted. The nitrogen content varied from 3.70 to 6.80 percent, dry basis. Acidification increased the amount of nitrogen from 0.72 to 2.88 percent. On an average of 10 analyses each, of sludge with and of sludge without acidification, the acidified cake contained 5.85 percent and the non-acidified cake 5.08 percent organic nitrogen. The ether soluble was also increased from 3.67 to 5.85 percent.

Cotton duck cloths gave as satisfactory results as linen. For the 52 tests, two complete sets of cotton duck cloths were used.

The addition of ribs made a sectional plate, forming the cake in smaller sections, and increasing the relative drainage area as compared to cake area. The improvement was pronounced on a ⅞ inch cake basis, the cake yield being practically doubled.

ACIDIFICATION OF SLUDGE. Acidification with sulphuric acid was helpful in reducing the moisture content of the sludge and conditioning it so that it would release its moisture more readily. This effect was more clearly demonstrated by the filter pressing, where the capacity of a press was practically doubled.

SETTLING TANKS. In hopper bottom tanks, bottom slopes of 30 deg. with the horizontal were found insufficient. A 45 deg. slope was not entirely satsifactory. A slope of 1.8 vertical to 1 horizontal (61 deg.) proved satisfactory. With hopper bottomed vertical flow tanks a period of about 1.5 hr. was used. The best results were obtained with the inclined baffle tanks.

FILTROS PLATES. The first lot of plates proved soft. They were replaced by satisfactory plates by the makers. The

tests show the need of supporting each plate on 4 sides in a sturdy box. There was a marked increase in the air pressure, equivalent to 3.2 ft., during the period of April 23 to Nov. 14, 1917. The clogging was largely due to rust.

EFFECT OF SCREEN ON ACTIVATED SLUDGE. The use of the fine screen seemed advisable to remove much comparatively inert material which is slow to oxidize. The runs made with a screen did not appear to differ greatly in character of effluent from those without. The coarser material, however, deposited in various undesirable places. When the screen was not used, additional air was required to keep coarser material in suspension.

## SCREENING.

SCREEN TESTS. The rotary screen was regularly scrubbed with a hot solution of soda ash every Sunday. Steam should be supplied on an actual installation.

The amount of water used for cleaning was high, on account of the small size of the apparatus and its rough construction, the use ranging from 10.5 to 29.0 percent of the flow during the screening period. This can be reduced by other methods of cleaning.

The 30 mesh screen was operated for 224 days, handling a total of about six million gallons of sewage. A recovery of 858 lb. of dry screenings per mil. gal. of sewage screened was obtained, equivalent to a reduction of 18.8 percent of the total suspended solids.

The 20 mesh screen was operated for 138 days, handling a total of about five million gallons of sewage. A recovery of 368 lb. of dry screenings was obtained per mil. gal. of sewage screened, equivalent to a reduction of 9.6 percent of the total suspended solids.

The crude sewage, however, averaged 547 parts per million during the 30 mesh run and 460 parts per million during the 20 mesh run.

During the 24 hours of the day the highest rate of accumulation was between 3:30 and 5:30 p. m.

SCREENINGS COMPOSITION. The wet screenings averaged a moisture content in percent of 81.2 on the 30 mesh and 80.9 on the 20 mesh. The screenings were largely hay, chaff, paunch manure, hair, skin, flesh, undigested food, etc. The screenings contained in percent dry weight, fixed matter 4.7, volatile 93.3, organic nitrogen 2.18, and ether soluble 5.93.

SCREENING EFFECT ON BIOCHEMICAL OXYGEN DEMAND. A few comparative results obtained on the 30 mesh screen indicate a percent change in biochemical oxygen demand ranging from an increase of 4 to a reduction of 10. Consequently the improvement in oxygen demand effected by fine screening is slight.

SCREEN AT PACKINGHOUSE. A 40 mesh cylindrical screen of the North type (flow from inside to outside) was tested at the hog packing plant of Boyd-Lunham Co. During the entire 6 day test, 9,608 lb. of wet screenings, or 1,510 lb. of dry screenings were recovered from 766,000 gal. of sewage screened. This is equivalent to a recovery of 1,270 lb. of dry screenings per mil. gal. or a reduction in suspended matter of 18.8 percent. The screenings contain on a dry basis from 92.5 to 95.3 percent volatile matter, 4 to 6.6 percent organic nitrogen, and 22 to 23 percent ether soluble.

## ACID TREATMENT.

Tests were made in 1914 and 1915 on the acid treatment of the crude sewage, using sulphuric acid. 66 deg. Bé. acid was applied on weekdays, but not on Sundays, holidays, or at night. The procedure endeavored to make the sewage slightly acid. In general a removal was obtained of 70 percent of the suspended matter and 57 percent of the biologic oxygen consumed. From 31 to 69 percent of the ether soluble material was removed.

With an excess of acid somewhat better removal of suspended matter was obtained than by plain sedimentation.

Scum formed very slowly and was small, in amount, compared to plain sedimentation in Dortmund tanks.

The accumulation of sludge and scum varied from 6.3 to 8.0 cu. yd. per mil. gal.

| Tank | Cu. Yd. Per Mil. Gal. | | | Period of Observation |
|---|---|---|---|---|
| | Sludge | Scum | Sludge and Scum | |
| Dortmund C | 3.1 | 2.7 | 5.8 | June 24, 1913 to June 14, 1914 |
| Dortmund D | 6.1 | 3.5 | 9.6 | Sept. 16, 1912 to July 7, 1913 |
| Emscher E | 6.8 | 1.3 | 8.1 | Sept. 16, 1912 to June 1, 1914 |
| Chem. Precip | 12.7 | ........ | 12.7 | Aug. 28, 1913 to June 1, 1914 |
| Acid | 6.7 | 0.9 | 7.8 | |

The sludge is somewhat higher in nitrogen than Imhoff or plain settling and is the highest of all the sludges in ether soluble

matter. The sludge was foul in odor, drying much less rapidly on sand beds than Imhoff tank sludge.

## IMHOFF TANK.

Operation of the Imhoff tank was begun on Sept. 16, 1912 and continued until March 6, 1918. The tank was operated as a radial downward and upward flow unit until March 9, 1914, when it was remodelled. On March 19, 1914, it was put into service as a horizontal flow tank. The water depth of the tank was 17 ft., the interior diameter 9 ft.

The results obtained were as follows:

| Average Upward Velocity Ft. per Hr. | Detention Period Hours | Percent. Removal Suspended Matter | | Number of Months Averaged |
|---|---|---|---|---|
| | | Day Sewage | 24-Hour Sewage | |
| ORIGINAL TANK. VERTICAL FLOW | | | | |
| 1.9 | 4.0 | 52 | 45 | 2.5 |
| 2.5 | 3.0 | 50 | 47 | 2.0 |
| 3.8 | 2.0 | 51 | 48 | 5.5 |
| 5.0 | 1.5 | 53 | 50 | 4.0 |
| REMODELLED TANK, HORIZONTAL FLOW | | | | |
| 12.5* | 1.4 | 54 | 42 | 34.0 |
| 9.2* | 1.9 | 64 | 59 | 5.3 |
| 6.0* | 2.9 | 62 | 57 | 8.0 |

*Horizontal velocity, ft. per hr.

In general higher reductions were obtained with the horizontal flow than with the original installation, except for the 1.4 hr. detention period. This may be due to the fact that during the last 2 years of operation when the tank was running on a 1.4 hr. detention period, less attention was paid to efficient operation and control.

The reduction in biochemical oxygen demand on the day sewage averaged 29 percent for the 1.4 hr. period and 27 percent for the 2.9 hr. period.

The ebullition of gas from the sludge chamber was continuous during the entire life of the tank. Although generally inoffensive, hydrogen sulphide was sometimes noted. Scum was almost continuously present on the surface of the gas vents.

A thin grease scum persisted on the surface of the settling chamber, and was removed at the rate of 0.4 cu. yd. per mil. gal.

The rate of accumulation of sludge and scum is summarized as follows, up to March 8, 1916, for the remodelled tank, horizontal flow.

| Detention Period Hours | Cubic Yards per Million Gallons | | |
|---|---|---|---|
| | Sludge | Scum | Total |
| 1.4 | 7.6 | 0.9 | 8.5 |
| 1.9 | 7.5 | 0.3 | 7.8 |
| 2.9 | 10.3 | 0.5 | 10.8 |

These agree very closely with the average obtained between Sept. 16, 1912, and June 1, 1914, with a removal in cu. yd. per mil. gal., of sludge 6.8, scum 1.3 and total 8.1.

The moisture content of the sludge was higher than in many domestic installations. The nitrogen content was lower than in activated sludge.

IMHOFF SLUDGE DRYING. The sludge was uniformly black or dark gray in color, flowed freely and drained readily on the drying beds. Sludge dried in the warmer months readily to a spadeable condition in 4 to 7 days. In the winter under glass, a couple of tests in February and March showed 4 and 5 days required for removal.

## SPRINKLING FILTER.

The sprinkling filter was 6 ft. in depth, consisting of 5 ft. 6 in. of 1¼ to 2 in. limestone, overlying 6 in., of 2 to 4 in. stone. It was dosed with a Taylor circular spray nozzle (spraying 14 ft. 9 in. diameter) with a cam device for regulating the head on the nozzle. The effluent from the Imhoff tank was applied to the filter. Operation began on September 22, 1913, and concluded on December 9, 1917.

Operation began at a nominal net yield rate of 0.786 mil. gal. per acre per 24 hr. This was maintained until April 1, 1914, when it was increased to 0.987 mil. gal. per acre per 24 hr. On Aug. 4, 1914, it was again increased to 1.313 mil. gal. per acre per 24 hr. On Dec. 1, 1914, this was reduced to 0.965 mil. gal. per acre per 24 hr. On Nov. 1, 1915, this was reduced to 0.583 mil. gal. per acre per 24 hr. until Dec. 8, 1917. These rates are actual net yields.

The work of the filter was satisfactory. Suspended matter varying between 43 and 340 p. p. m. was applied, the removal varying, on monthly averages of the day and night samples, from about 48 percent to an increase of 63 percent. Nitrification became well established within a few days after the start and was well maintained, the nitrates in the effluent varying from 5.3 to 34 p. p. m. on monthly averages. Relative stability and dissolved oxygen samples were taken four times daily at 3 a. m., 9 a. m., 3 p. m.

and 9 p. m. The former were incubated at room temperature for 10 days. Dissolved oxygen was nearly always present in the effluent.

For the entire period of the operation of the filter, an average relative stability of 68.7 was obtained. During the winter months the monthly averages varied with the rates, running between 18 and 29 on the high rate in 1914-1915 and between 24 and 79 on the lower rates in the other winters, whereas during the summer the averages were higher, from 61 to 98, with one month only (July, 1915) at 40.

The performance of the filter was best emphasized by the reduction in oxygen requirements. 990 p. p. m. of oxygen were required for complete stability of the crude sewage from Center Ave., whereas the average requirement for the filter effluent was about 137, a reduction of 87 percent made by tank and filter. These figures were for the strong day sewage.

During the four years of operation there was but slight pooling during the winter and no signs of any permanent loss of capacity by retention of fats or solids. Evidently the unloading maintained a balance. With the high temperature of this sewage, cold winter weather causes little difficulty in operation.

The conclusion is that a coarse sprinkling filter, as described, can be dosed with well settled sewage at rates from 0.6 to 1.0 mil. gal. per acre per 24 hr. and a net yield obtained of at least 0.6 mil. gal. per acre per 24 hr. With an actual plant, in which the flow decreased at night, and with better attention to the dosing, it is believed net yields of at least 0.75 mil. gal. per acre per 24 hr. can be maintained.

SECONDARY SETTLING. The effluent from the filter was passed through a small secondary basin. Two types were tried.

In the Dortmund tank, the detention period was 1.0 hr. the greater part of the time and the upward velocity from 2.4 to 3.5 ft. per hr. Under these conditions, the removal of residual suspended matter varied from an increase of 7 percent on one month to a removal of from 14 to 54 percent based on monthly averages.

In the Imhoff tank of the flowing through type, the detention period was 2.2 hr. at first and later 1.6 hr. The removal of residual suspended matter varied from 44 to 73 percent based on monthly averages.

Sludge and scum accumulated at a rate varying from 0.5 to nearly 8.0 cu. yd. per mil. gal. between individual measurements in the Dortmund tank. The percentage of volatile matter in the sludge recovered from both tanks was appreciably lower than for the fresh sludges from the preliminary tanks, while the nitrogen content was distinctly higher. The nitrogen content, however, is lower than for the activated sludge.

Secondary settling basins are necessary on account of the large amounts of suspended matter applied to the filter and unloaded. Owing to the excessive scum formation at times and the comparative difficulty of maintaining single chamber tanks, a double deck type of tank seems preferable. Possibly a shallow tank with slightly coned bottom with a revolving squegee collecting the settled solids to the center, with a mechanical skimming attachment on the surface such as the Dorr Co. make, might prove practicable.

## OXYGEN REQUIRED.

Comparison of the total oxygen required for the oxidation of the sewage showed a demand of 990 p. p. m. at Center Ave. on the strong day sewage.

Fine screening (20 to 30 mesh), even though removing 25 percent of the suspended matter, had small effect on the stability of the liquid, reducing the oxygen demand from 0 to 8 percent.

Settling in the Imhoff tank made a reduction on the day crude sewage, in the oxygen requirement, between 23 and 32 percent.

Settling in the Imhoff tank, followed by the sprinkling filter, made a total reduction on the day crude sewage in the oxygen requirement, of 87 percent.

The activated sludge process made a total average reduction on the day crude sewage in the oxygen requirement to 42 p. p. m. or a reduction of about 96 percent.

The acid treatment of the sewage made a total reduction on the crude sewage in the oxygen requirement of about 40 percent.

## CHAPTER I.

### THE STOCKYARDS AND PACKINGTOWN INDUSTRY.

In the Report on Industrial Wastes from the Stockyards and Packingtown in Chicago made to the Board of Trustees of the Sanitary District of Chicago in October, 1914, the first chapter covers a complete summary of the industry up to 1914. The data contained therein have not been entirely repeated here, but the essential statistics have been brought up to date and given in their respective place. For those who have not available the original report, a few notes on the general growth of the industry and the situation may be of interest.

For years Chicago has been the center of stockyards and packing interests. A large community of plants has grown up in the vicinity of 39th and Halsted Streets on the South Side, occupying over one square mile, with stockyards and packing houses, and including all the scattered plants, nearly one and one-half square miles. The industry has grown from small beginnings, with various shifts in location. In 1848, John B. Sherman started the Old Bull's Head stockyards at the corner of Madison Street and Ogden Avenue. This site proving unsatisfactory, a new site was selected at Cottage Grove Avenue and 30th Street, known as the Sherman Stockyards. In 1865, the site was again changed to a half-section bounded by 40th and 47th Streets, and by Halsted Street and Center Avenue, at that time largely a swamp far outside the city limits. At first, the yards covered 120 acres, with 2,000 cattle pens, which grew in 1901 to 340 acres with 5,000 pens.

From 1865 on, the industry developed in one central location. As nearly as can now be learned, drainage was into the south branch of the Chicago River, a very sluggish stream, utterly inadequate to receive the wastes of even a young industry. Complaints began early and continued in years, lessened somewhat by the endeavors of the packers to recover more completely the by-products. In the early days, the problem of disposing of the offal resulting from the slaughter of cattle, sheep and hogs, was very troublesome. Even its value as fertilizer was unknown. Blood was allowed to run into the river, while heads, feet, tankage and general refuse were hauled out on the prairies and buried. A few

began to dig up this material, and convert it into glue, tallow, oil and fertilizer in small factories. For a while the offal was given to any one who would cart it away. Various products of fair quality were made in small factories, at large profits which attracted so much competition that buyers bid up the price of offal to a high figure.

With the perfecting of a direct heat drier in 1877, the packers began to enter the fertilizer industry, making the profits for themselves. Gradually other by-products were utilized, by the packers themselves, so that today practically every part of the animal is used in some way in factories belonging to the large packing houses. In the small houses, slaughtering largely for intra-state or local trade, early conditions still obtain. Blood, offal, and even tankage frequently are discharged into the sewer in a way not tolerated in the large houses. Today in the large houses, an attempt is made to save practically everything except the squeal, and even that the packers jokingly say is canned by a phonograph. In the pursuit of returns, grease is skimmed from one of the main sewer outfall, at Center Avenue, and from the immediate surface of the river.

The endeavor of the industry, to secure economic recoveries has not, however, carried the efforts so far as to retain material of importance, not necessarily from the manufacturing standpoint, but from the standpoint of sewage disposal. There is still much material which passes away, in the aggregate thousands of tons a year, to which the practical manufacturer attaches little importance. To the sanitary engineer these wastes, containing large amounts of suspended matter with a liquid highly putrescible, are of great importance. For many years there has been a strong feeling that industrial waste of highly putrescible character is concentrated in the region along the South Fork of the Chicago River known as Bubbly Creek, yet no definite data had been found on which to base any recommendations for its treatment or use.

Many sanitary engineers of standing have felt that the legal minimum rate of flow (3.33 cu. ft. per sec. per 1,000 population) prescribed for the Sanitary District by its charter was too low to care for the industrial load on the main channel in addition to the sewage of purely human origin. Prior to filling up the West Arm, west of Ashland Ave. in 1917, it was evident that sedimentation did occur markedly, both of organic and mineral suspended matter. The velocities of flow were not sufficiently high to scour. The period of settling was over 30 hours. The condition of the South

Fork, however, as a whole, has been vastly improved by the construction of the 39th Street pumping station, and the use of the flushing pumps, but permanent improvement will not ensue until the quality of the waste discharged into the river is distinctly improved, and large amounts of suspended matter removed.

From time to time substantial deposits have been dredged out by the United States, the City of Chicago, the Sanitary District, and private corporations. The amount of material so removed amounts to several hundred thousand cubic yards, since the opening of the Drainage Canal in 1900. Gaseous ebullition from submerged banks of foul putrefying organic matter may still be seen at intervals along the South Fork. A record of soundings in the West Arm, west of Ashland Ave., showed that over a period of thirteen years, from 1895 to 1908, the shoaling has continued at a rate of 0.42 feet per year. In this dead end, fed solely by the Ashland Ave. and Robey St. sewers, and a little surface water from the original bed of the old West Arm east of Western Avenue, the source of the deposits was at once evident. During the work preliminary to the opening of the conduit from the West Arm through Western Avenue to the Drainage Canal, the Sanitary District removed approximately 100,000 cu. yd. of material from the West Arm west of Ashland Avenue. Of this it is estimated that over 50 percent was typical sludge of sewage origin, in various stages of putrefaction.

## PREVIOUS INVESTIGATION.

Early in the history of the Sanitary District it was realized that something must be done to improve the condition of Bubbly Creek. In 1890 steps were taken by L. E. Cooley, then Chief Engineer, towards a comprehensive investigation covering gauging of sewers and chemical analysis, but little data was obtained.

Ten years later in the report of the sanitary investigations of the Illinois River and its tributaries (Illinois State Board of Health, 1901) Professor J. H. Long made a special report on the chemical and bacterial examination of the waters of the Illinois River and its principal tributaries. In this report he commented on the conditions existing in Bubbly Creek and the north branch of the Chicago River.

The investigations covered in the Report of Industrial Waste of October, 1914, were made in the period between January, 1911, and October, 1914. The results of that investigation are summarized in Appendix 4.

## PRESENT INVESTIGATION.

Since 1914 the work has been continued, and the investigation of the individual houses brought up to date. Further, in 1915, experiments were undertaken on the activated sludge process. The preliminary results, obtained on a very small scale (Chapter 6), were so encouraging that in October the construction of a larger scale test plant was begun. This was put into service on January 10, 1916. The plant is described in Chapter 2. From time to time the plant was changed to study the variations caused by different methods of construction and operation, with the results given herein. The plant was kept in operation with considerable difficulty during 1918, owing to the war, and was finally dismantled in September of that year.

Based on the results available in 1916, a preliminary statement was made by W. D. Richardson, representing the packers, and Langdon Pearse, representing the Sanitary District, in which both agreed that the activated sludge process was the most likely to prove successful in handling the industrial waste from Packingtown. This was followed in April, 1917, by a report, in which the scheme for the collection of the sewage and its treatment was worked out at considerable length in a preliminary way with estimates of cost. This was supplemented in 1917 by a comprehensive survey of the existing houses to determine their flow and amount of pollution, on which a report was made by the Chief Engineer in November, 1917, giving the relative liability of the packers (Appendix 2). The cost of this survey was paid by the packers. The survey showed that a plant would have to be based on 58 mil. gal. per 24 hr. instead of 48 mil. gal. per 24 hr. as figured in 1916.

During the war, negotiations were at a standstill. In 1919 however, the matter of adjustment of costs and procedure was taken up with vigor and pushed. The attendance of representatives of municipal organizations was invited at the conferences of the trustees and representatives of the packers. As a result, the packers have offered to pay sixty percent of the cost of treatment and also of the net operating cost if the District will assume the remaining forty percent of the cost. A suggested form of contract has been drafted and is now under consideration.

SITE. The Sanitary District has available the right to use 7.8 acres at the forks of the east and west arms of the south fork of the south branch of the Chicago River, on property owned by

## TABLE 1

RECORD OF ANIMALS LEFT IN CHICAGO AND PRESUMABLY SLAUGHTERED. 1866 TO 1919

Compiled from Statistics Furnished by the Drovers' Journal

| Year | Cattle | Calves | Hogs | Sheep | Total Head |
|---|---|---|---|---|---|
| 1866 | 129,314 | ........... | 478,871 | 132,540 | 740,725 |
| 7 | 125,608 | ........... | 937,613 | 130,949 | 1,201,170 |
| 8 | 108,537 | ........... | 686,453 | 189,257 | 984,247 |
| 9 | 108,385 | ........... | 575,564 | 231,382 | 915,331 |
| 1870 | 141,255 | ........... | 768,705 | 233,141 | 1,143,101 |
| 1 | 141,132 | ........... | 1,218,697 | 179,969 | 1,539,796 |
| 2 | 174,050 | ........... | 1,417,029 | 165,195 | 1,756,274 |
| 3 | 187,247 | ........... | 2,240,193 | 176,499 | 2,603,939 |
| 4 | 221,037 | ........... | 2,028,018 | 148,100 | 2,397,155 |
| 5 | 224,309 | ........... | 2,329,467 | 175,344 | 2,729,120 |
| 6 | 299,021 | ........... | 3,058,371 | 168,170 | 3,525,562 |
| 7 | 329,749 | ........... | 3,074,749 | 154,886 | 3,559,384 |
| 8 | 393,960 | ........... | 5,072,748 | 153,693 | 5,620,401 |
| 9 | 488,629 | ........... | 4,755,969 | 165,853 | 5,410,451 |
| 1880 | 495,863 | ........... | 5,664,565 | 179,300 | 6,339,728 |
| 1 | 559,837 | 15,483 | 5,185,165 | 239,686 | 6,000,171 |
| 2 | 661,521 | 14,636 | 4,069,782 | 314,687 | 5,060,626 |
| 3 | 912,186 | 17,552 | 4,321,233 | 375,454 | 5,626,425 |
| 4 | 1,025,813 | 21,264 | 3,959,352 | 511,275 | 5,517,704 |
| 5 | 1,161,524 | 24,890 | 5,140,089 | 743,321 | 7,069,725 |
| 6 | 1,259,225 | 32,633 | 4,627,977 | 741,878 | 6,661,713 |
| 7 | 1,590,525 | 49,903 | 3,658,851 | 915,768 | 6,215,047 |
| 8 | 1,643,158 | 72,423 | 3,169,883 | 913,773 | 5,799,237 |
| 9 | 1,763,310 | 87,392 | 4,211,867 | 1,121,154 | 7,183,723 |
| 1890 | 2,223,971 | 113,559 | 5,678,129 | 1,256,813 | 9,272,472 |
| 1 | 2,184,095 | 157,052 | 5,638,291 | 1,465,332 | 9,444,770 |
| 2 | 2,450,121 | 166,572 | 4,788,290 | 1,661,711 | 9,066,694 |
| 3 | 2,233,243 | 196,725 | 3,908,318 | 2,588,309 | 8,926,595 |
| 4 | 2,023,625 | 149,061 | 5,018,170 | 2,766,327 | 9,957,183 |
| 5 | 1,803,466 | 158,858 | 5,784,670 | 2,932,903 | 10,679,087 |
| 6 | 1,782,150 | 131,880 | 5,763,160 | 3,029,416 | 10,706,606 |
| 7 | 1,711,532 | 111,759 | 6,733,740 | 2,968,530 | 11,525,561 |
| 8 | 1,615,255 | 104,889 | 7,476,570 | 3,046,014 | 12,242,728 |
| 9 | 1,702,572 | 118,489 | 6,488,431 | 3,295,841 | 11,605,333 |
| 1900 | 1,794,397 | 122,250 | 6,656,881 | 3,061,631 | 11,635,159 |
| 1 | 1,999,820 | 162,437 | 6,989,532 | 3,280,793 | 12,432,582 |
| 2 | 2,031,644 | 224,977 | 6,643,440 | 3,683,988 | 12,584,049 |
| 3 | 2,163,031 | 245,499 | 6,088,369 | 3,582,651 | 12,079,550 |
| 4 | 2,922,853 | 244,083 | 5,612,724 | 3,142,360 | 11,922,020 |
| 5 | 2,010,256 | 354,008 | 5,697,632 | 3,380,693 | 11,442,589 |
| 6 | 2,176,252 | 389,944 | 5,533,457 | 3,464,176 | 11,563,829 |
| 7 | 1,853,240 | 397,097 | 5,490,159 | 3,069,391 | 10,809,887 |
| 8 | 1,683,870 | 390,322 | 6,261,707 | 3,137,817 | 11,473,723 |
| 9 | 1,662,126 | 380,138 | 4,955,025 | 3,501,103 | 10,498,392 |
| 1910 | 1,741,074 | 464,742 | 4,384,468 | 3,735,346 | 10,325,630 |
| 1 | 1,715,279 | 493,561 | 5,576,638 | 4,452,810 | 12,238,288 |
| 2 | 1,681,136 | 482,932 | 5,608,415 | 4,880,873 | 12,653,356 |
| 3 | 1,530,625 | 356,921 | 5,898,292 | 4,453,610 | 12,239,448 |
| 4 | 1,430,770 | 346,905 | 5,327,454 | 4,105,081 | 11,210,210 |
| 5 | 1,881,049 | 411,879 | 6,519,125 | 3,252,010 | 12,064,063 |
| 6 | 2,028,504 | 495,079 | 7,783,497 | 3,461,619 | 13,768,699 |
| 7 | 2,374,400 | 578,673 | 6,224,333 | 2,758,802 | 11,936,208 |
| 8 | 2,800,051 | 622,329 | 8,031,478 | 3,424,526 | 14,878,384 |
| 9 | 2,331,233 | 700,668 | 7,936,634 | 3,934,952 | 14,903,487 |

the Union Stockyards and Transit Company. For the construction of the plant, however, more acreage is required in order to keep down the cost of operation, which deep tanks would necessitate, and to have available area for development. An alternate site has been discussed just south of 39th St. and east of Ashland Ave. This would permit the filling of the west arm from the north side of west 39th St. to the east side of Ashland Ave. The legal com-

plications attendant to acquiring this site are being worked out. A third site may also be found. For the purposes of treatment it has been considered desirable, both from the financial and sanitary standpoint, to have a site close to the point of origin of the wastes, in order to avoid the decomposition, and possible nuisance which might accrue thereby, following prolonged transportation of such a waste.

MAGNITUDE OF PROBLEM. In order to show the magnitude of the problem, and its growth, particularly during the war, figures furnished by the Drovers' Journal have been compiled, giving the statistics of the head of cattle, hogs, sheep and calves used in the City. This represents very closely the total head slaughtered. The figures extend from the beginning of the Stockyards in 1866 to date (Table 1). In Fig. 8 are plotted the total head slaughtered each year as well as the total population of the City of Chicago, given by the U. S. census. For the period from 1910 to date, the weight of the animals killed has been estimated. The weight of the animals killed is more important than the number, because of the great difference in weight of the various classes handled (Table 2).

**TABLE 2**

AVERAGE WEIGHT OF VARIOUS ANIMALS AT UNION STOCKYARDS

| Year | 1915 | 1916 | 1917 | 1918 | 1919 |
|---|---|---|---|---|---|
| Cattle | 1046 | 987 | 939 | 941 | 936 |
| Calves | 35 | 43 | 50 | 55 | 63 |
| Hogs | 219 | 210 | 213 | 234 | 233 |
| Sheep | 79 | 79 | 78 | 78 | 76 |

Variations in the number of cattle and hogs killed are thus seen to have far more weight than the number of sheep or calves.

The increase in killing of cattle during the war pushed up the total weight markedly in 1915 and 1916 to a greater extent than the increase in numbers would indicate. At the time the report of 1914 was published, the curves showed a decrease in the killing at Chicago, since 1900, due to the increasing number of western packing centers at Kansas City, St. Joseph, Omaha, Fort Worth, etc. But with the increased demand for food products due to the European war, slaughtering in Chicago jumped from 10,300,000 head to 13,500,000 in 1916. It was the opinion of the packers in 1914 that the peak of the business growth in Chicago had been

reached, but the effect of the war upset all prophecies. In 1918 and 1919, the total killing again exceeded all past figures in weight, if not in numbers.

SEASONABLE DISTRIBUTION. From the standpoint of the operation of the canal, and the load of organic matter to be cared for, it is important that the seasonal distribution be known. The total head slaughtered has been averaged by months for the periods from 1901 to 1910 and from 1911 to 1919 inclusive (Fig. 9). The result show a slightly heavier load in the autumn and early winter than in the spring and summer months. A comparison of the diagrams for the two periods indicates practically the same seasonal distribution, the winter killing being somewhat the greater in the period, 1911-1919.

THE PACKING INDUSTRY. The processes involved in the houses in Chicago are still carried along substantially as indicated in the report of 1914. The information contained therein is not reprinted. Since issuing that report, however, considerable attention has been given in the operation of the larger houses to the retention of grease and to the evaporation of tank water to a greater extent than before. Even the smaller houses have done likewise. In addition Swift & Co., Wilson & Co. and Boyd, Lunham & Co., have installed fine screens on the outlet of the paunch manure presses, in an endeavor to retain some of the material escaping to the sewer. A test on the Boyd, Lunham & Co. screen is given in Chapter XI.

EXPERIMENTS BY PACKERS. In addition to the experiments described herein made by The Sanitary District of Chicago, some experiments were made privately by the packers on different sewer outlets. The results obtained by Armour & Company, so far as have been made public, are detailed in an article by Rudnick and Noble in the Journal of Industrial and Engineering Chemistry (Vol. 8, pp. 651-2). Swift & Company also built an activated sludge plant of considerable size on their outlet to the Ashland Ave. sewer. Owing to the war it was not completed for many months, and when operated was utilized largely to determine whether or not the sludge produced could be filter pressed. This plant included a screen of the Jennings type, aeration tanks and a sludge press of the plate type. Wilson & Company also made some tests on activated sludge and further tried out the use of an electrolytic plant of the Landreth type, using lime in connection with

the passage of electrical current between iron plates. The general purpose of these experiments was more to determine the character of the material recovered than to establish the degree of purification in an effluent. Consequently, the lime electrolytic process was abandoned because of the great amount of lime in the sludge. So far as can be ascertained, the results obtained by the packers on activated sludge were encouraging, and served a purpose in leading them to agree that the activated sludge process was the most practicable process for handling the sewage of Packingtown.

# CHAPTER II.

## DESCRIPTION OF TESTING STATION.

CONTINUITY OF INVESTIGATIONS. Operation of the Testing Station, described in the 1914 report, continued for some months with a few minor changes. The new Dortmund (tank C

**Plate 1. Center Ave. Testing Station from North. Original.**

in the 1914 report), was shut down on July 12, 1915. The old Dortmund tank (tank D) was kept in continuous operation until July 10, 1915, when it was remodelled for use in activated sludge experi-

**Plate 2. Center Ave. Testing Station from South. Original.**

Plate 3. Center Ave. Testing Station from West, Showing Activated Sludge Plant.

ments. The Imhoff tank (tank E) and the sprinkling filter were operated for over three years, until finally shut down on March 1, 1918. The grit chamber, controlling apparatus, and rotary screen were continued in operation with no alterations. The general arrangement is shown in Fig. 10 and 11.

Plate 4. East Arm of South Fork of South Branch of Chicago River from Racine Ave. Bridge, Looking East.

NEW PLANT. The activated sludge investigations developed gradually, starting with small galvanized iron tanks operated on the fill-and-draw principle. Later a plant capable of treating approx-

imately 75,000 gallons per day was constructed. As the experiments progressed this plant was altered in many ways.

SEWAGE PUMPS. Sewage was pumped by a vertical centrifugal pump with a rated capacity of approximately 250,000 gallons per 24 hr. The pump was set in a pump well, being submerged in the sewage flowing from the Center Ave. sewer. It was protected by a bar screen, set an an angle of 30 degrees with the horizontal, 9⅜ in. wide, constructed of ⅝ in. round bars with ⅝ in. clear openings. The pump was driven by a direct-connected squirrel cage motor of 3½ horse power, running at 850 r. p. m. A small galvanized iron shed covered both motor and pump.

An auxiliary centrifugal pump was also set in the pump well of capacity 250,000 gallons per 24 hr. at 720 r. p. m. This pump was belt-connected to a 3 h. p. 1800 r. p. m. motor.

GRIT CHAMBER. The grit chamber of capacity 87 gal. was supported on a trestle, with the flow line approximately 19 ft. above the pump. The sewage was pumped into a stilling basin built of a half barrel, which fed the grit chamber through a 4 in. pipe entering at the bottom at one end. The grit chamber was constructed of 2 in. stock, 20 ft. 6 in. long, 6 in. wide inside, varying uniformly from a depth of 19 in. at the inlet end to 13 in. at the outlet. Sludge was removed through a 4 in. waste pipe and valve near the inlet end. A scum board was placed 6 in. from the outlet, dipping about 2 in. below the surface of the sewage.

CONTROLLING APPARATUS. The pumpage was diverted in two ways. Part fed through the grit chamber to an orifice box built of 2 in. planks, originally containing three compartments for vertical orifice plates, on which a practically constant head was maintained by a waste weir extending the entire length of the box. The surplus sewage was wasted through a 3½ in. pipe overflow to a second orifice box below, where the head over three 1⅜ in. horizontal circular orifices was measured to determine the total amount of sewage passing the grit chamber. The upper box also measured the flow to the Imhoff tank and sprinkling filter, the sewage flowing to the tank through an open wood flume 3½ in. wide. The sewage for the activated sludge plant was pumped direct to a separate orifice box containing 6 horizontal orifices discharging directly to therotary screen before entering the aerating tanks.

ROTARY SCREEN. The rotary screen (Fig. 12) was of the Weand type, cylindrical in shape, 2 ft. 4 in. diameter by 4 ft. 8 in.

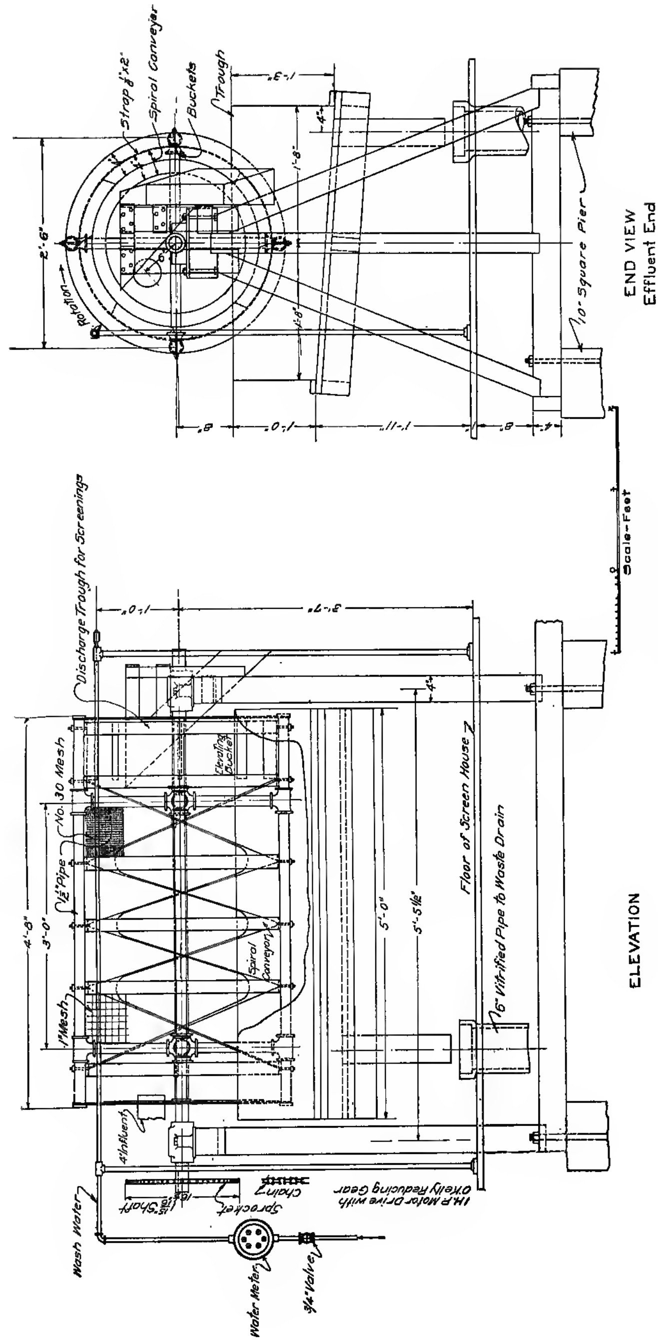


Fig. 12. Rotary Screen.

long, framed with 1½ in. pipe and fittings, and bands of strap iron. The screen was covered with a galvanized iron mesh 1 in. wide, supporting the fine brass screen, at first with 30 meshes per inch, and later with 20 meshes per inch. The screen was driven about 7 r. p. m. by a 1 h. p. motor and a reduction gear.

Raw sewage entered the screen at one end. The screen was cleaned by jets of water from perforated pipe placed directly above the cylinder. The screenings accumulated inside, being carried forward by a spiral worm toward the outlet end, where they were discharged into a galvanized iron can, drained and weighed.

IMHOFF TANK. The Imhoff tank (Tank E) was built of 2⅝ in. fir staves, with an inside diameter of 9 ft. and had a total depth below the flow line of 17 ft. Originally the tank was of the radial flow type, with an upper or settling chamber, and a lower or sludge digestion compartment. Sewage entered at the center through a small pipe ring, with eight outlet nipples, passing radially downward and under a baffle, and rising to the peripheral effluent ring. The settling solids, passing into the lower compartment, were automatically trapped. A central gas vent provided for the escape of the gases of decomposition. In March, 1914, the tank was remodelled into a horizontal flow tank.

The original tank had a settling capacity of about 2,240 gal., and a sludge capacity of 4,160 gal.,—a ratio of 1 to 1.85. In the remodelled tank, the settling capacity was reduced to 1,190 gallons, increasing the sludge storage to 4,390 gallons, or a ratio of 1 to 3.69. The gas vent of the original installation was 8.8 percent of the total tank area, but in the remodelled tank this was increased to 34 percent.

SPRINKLING FILTER. The sprinkling filter was 14 ft. 9 in. square, inside, with a total effective stone depth of 6 ft., of which the upper 5 ft. 6 in. consisted of 1¼ to 2 in. stone, underlaid by 6 in. of 2 to 4 in. stone. The filter was provided with a false bottom for collection of the filter effluent. The top was surrounded with a wind shield 3 ft. 6 in. high. It was dosed by a ⅞ in. Taylor nozzle, the head on which was varied by a butterfly valve in the supply line actuated by a motor driven cam of such shape as to produce approximately uniform distribution of the spray over the surface. The gross area of the filter was 0.005 acre.

SECONDARY SETTLING BASIN. No secondary settling basin was provided when the filter was started, but on Nov. 25,

1913, a small basin of the Dortmund type was put into operation. This basin was 3 ft. in diameter with an effective depth of 5 ft. 9 in. and with a conical bottom sloping at an angle of 40 degrees with the horizontal toward a central sump 6 in. deep and 9 in. in diameter. Sewage was admitted through a 1½ in. pipe in the center of the basin at a depth of 2 ft. 5 in. and the effluent was collected over a peripheral weir. On April 1, 1914 the depth of admission of the influent was increased to 3 ft. 7 in. and was thus continued until November 11, 1914, when the basin was abandoned. On December 23, 1914, a new secondary basin was put into operation and continued until December 7, 1915, when it too was abandoned, and the filter effluent thereafter discharged without further treatment. The new basin was of the horizontal flow Imhoff type constructed in a wooden tank, formerly used for lime mixing in the experiments on chemical precipitation, 4 ft. 8 in. in diameter and 3 ft. 6 in deep. The settling chamber was 20 in. wide and 2 ft. deep to the admission slots to the sludge chamber, the sewage entering at one side and flowing across the tank and back again around a central baffle to the effluent collector, making a total travel of about 9 ft. The settling chamber had a capacity of about 150 gal.

SLUDGE BEDS. The sludge beds, located east of the Imhoff tank, were built up of 2-in. dressed lumber. Each of the original six beds was 7 ft. 9 in. square, although later several were subdivided. The bottom was sloped about 2 in. from the sides toward an 1¼-in. underdrain at the center. The filtering material consisted of approximately 5 in. of graded gravel overlaid by 1 to 2 in. of torpedo sand. The total height of beds above the sand layer was 2 ft.

## ACTIVATED SLUDGE EQUIPMENT.

PRELIMINARY TESTS. The first activated sludge experiments were made in two galvanized iron tanks, one 10 ft. high, 2 ft. diam., holding approximately 210 gal., the other 9 ft. high, 2 ft. diam., holding approximately 190 gal. The bottom in one consisted of 3 layers of brass screen, 40, 60, and 100 mesh, the latter on top. In the other, during the first month of operation, air was distributed through a series of perforated ½ in. galvanized iron pipes. Afterwards a filtros plate was cemented into a wooden frame fitting the bottom of the tank. Air was furnished by a Gardner-Rix air compressor, and measured by a gas meter.

The results obtained in these small tanks indicated the advisability of constructing a large scale plant, to operate on a continuous flow basis.

LARGE SCALE PLANT. The activated sludge plant, at first, consisted of the rotary screen, four aeration tanks, one tank for settling the aerated sewage, one sludge storage tank, two blowers with motors for supplying air, a sludge pump for returning the sludge to the aeration tanks from the settling tank, or sludge storage tank, and a Venturi meter on the air, with recording apparatus (Figs. 10 and 11).

The four aeration tanks (tanks 3, 4, 5, and 6, Fig. 13) were each 6 by 23 ft. in plan, 12 ft. deep, inside dimensions, with filtros plates set in hopper bottoms for the distribution of air. The capacity of each tank was about 11,000 gallons to the flow line. The tanks were connected in series, and provided with inlet and drain pipes, for operating separately on the fill-and-draw plan, as well as a whole, with a continuous flow. The air system consisted of a main header to each tank, from which branch pipes fed each set of plates. Venturi meters (3 in. tube and 1½ in. throat) were provided on the main header line in a by-pass to check up the flow of air to each tank.

Settling tank 7 (Fig. 14) was 12 ft. in diameter with 12 ft. staves, built with a hopper bottom of the Dortmund type with a slope of 0.6 vertical to 1.0 horizontal. The sewage entered the tank at the center near the bottom, through a 3 in. pipe, the settled sewage flowing off at the top around a peripheral weir. A sludge pipe was provided for discharging sludge onto the drying beds, and to the sludge pump. The new Dortmund tank served as a sludge storage tank, and also was available as a settling tank for one of the aeration tanks.

Two rotary blowers of the Connersville make, Boston type, supplied the air, one with a capacity of 300 cu. ft. per min. against a possible pressure of 6 lb. per sq. in., driven by a 20 h. p. motor, the other with a capacity of 150 cu. ft. per min. against a possible pressure of 10 lb. per sq. in., driven by a 10 h. p. motor.

This equipment was operated from January to October, 1916, several minor changes being made, from time to time. On October 19, 1916, settling tank 7 was abandoned. The old Dortmund tank (tank D) was remodeled and used as a settling tank (Fig. 14). Two sludge concentration tanks and a horizontal flow settling tank were added to the equipment. The old Dortmund tank as remodelled

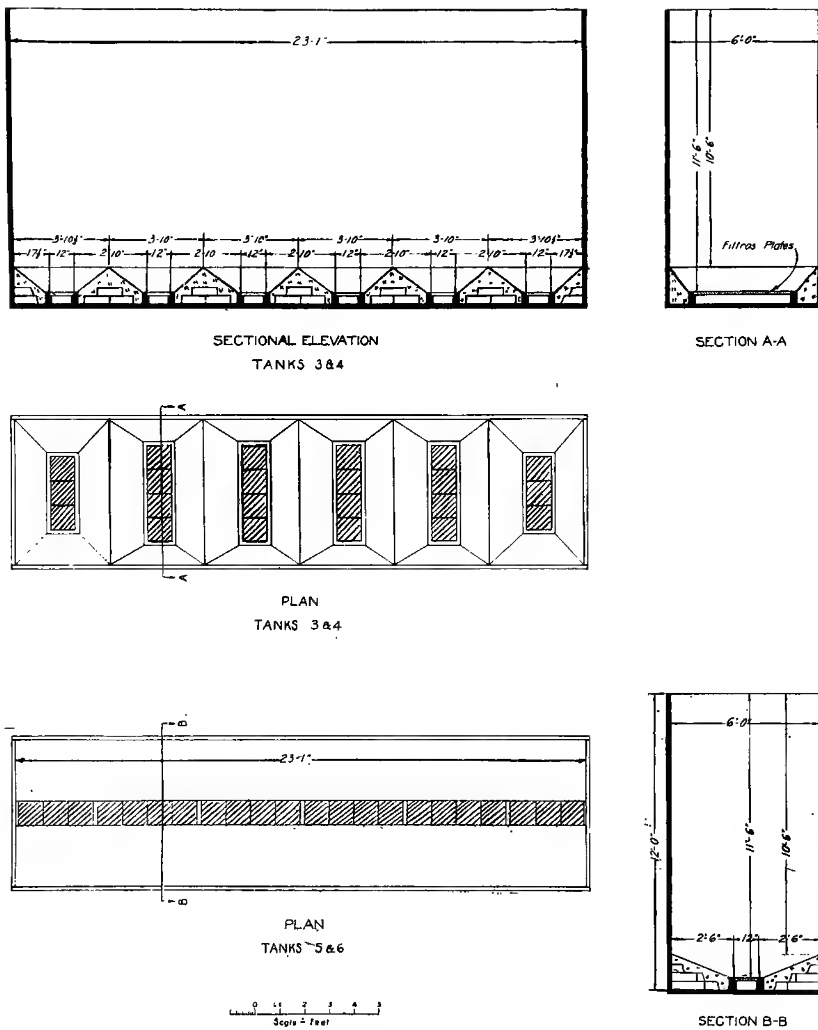


**Fig. 13. Aeration Tanks.**

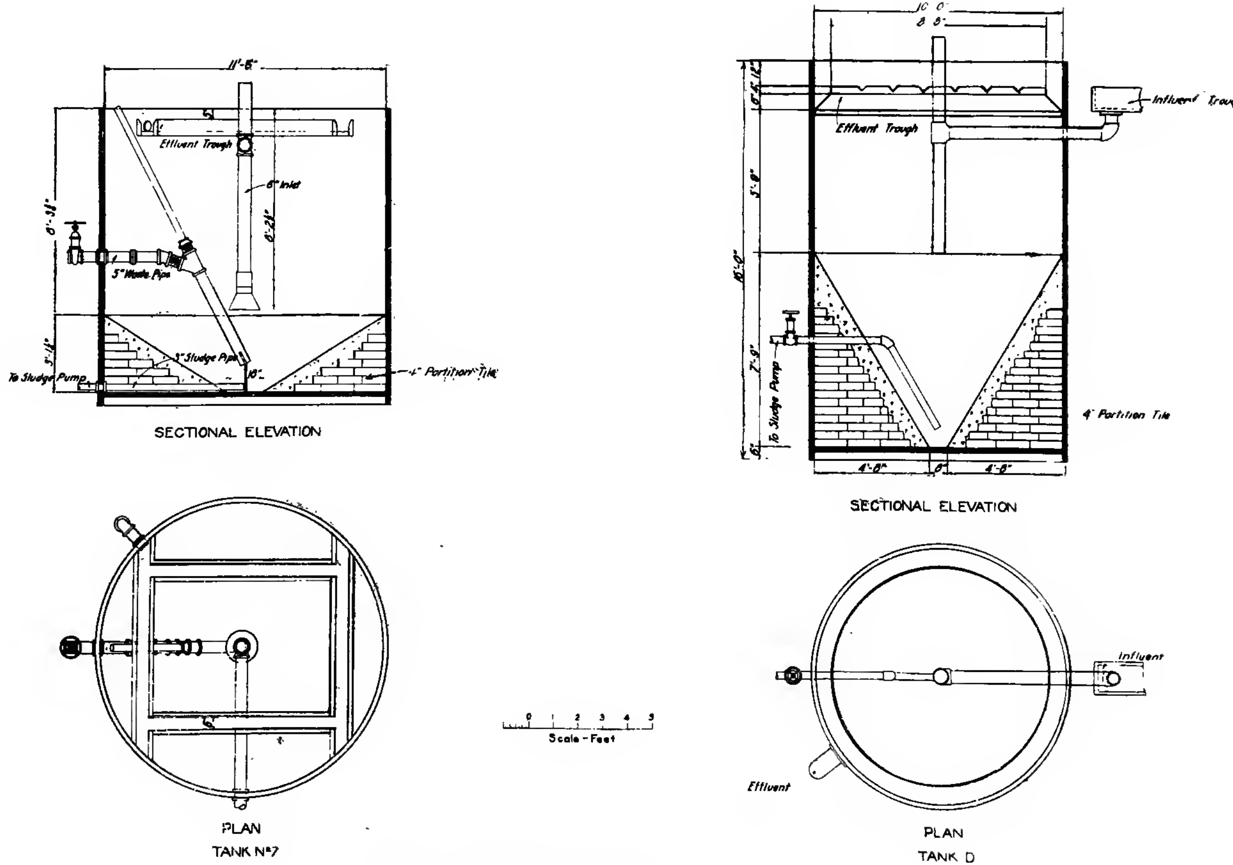


Fig. 14. Settling Tank 7 and Tank D. Dortmund Type.

was 10 ft. diam. with 16 ft. staves, built with a hopper bottom with a slope of 1.8 vertical to 1.0 horizontal. The sewage entered at the center through a 3 in. pipe, 7 ft. 9 in. below the top, the settled sewage rising and passing off in a peripheral trough, with a sloping bottom. A sludge pipe was provided for use both in discharging sludge onto the drying beds, and feeding sludge to the sludge circulating pump. The tank was also fitted with a sludge air lift.

The two sludge concentration tanks (tanks A and B) were each 2 ft. diam. and 10 ft. and 20 ft. deep respectively. They were made of galvanized iron and fitted with pipes for filling and emptying through the bottom, with outlet pipes fitted to discharge onto the sludge beds.

The horizontal settling tank (tank 8, Fig. 15) was 5 ft. by 15 ft. in plan by 10 ft. deep, inside dimensions. The sewage entered 5 ft. from the top of the tank. The settled sewage flowed off in a moveable effluent trough. The tank had a hopper bottom with three compartments, of bottom slopes 2 vertical to 1 horizontal. Each hopper discharged through a sludge pipe connected into the main sludge line serving the pump, sludge beds, and sludge air lift.

MODIFICATIONS FOR SLUDGE RE-AERATION. The experimental work, up to March 27, 1917, indicated a possible advantage in the re-aeration of the sludge before its return to the aeration tanks. The plant was therefore remodelled toward that end, Tanks 3 and 4 were connected in series, the outlet end of tank 4 being connected to the main settling tank, tank D. Tanks 5 and 6 were also connected in series, but the outlet end of tank 6 was remodelled for a settling tank (Fig. 16), the other portion of the tank being used for sludge re-aeration. The piping was so arranged that sludge from the main settling tank, (tank D) could be pumped to either tank 5 or tank 6. The re-aerated and resettled sludge from tank 6 was returned to aeration tanks 3 and 4 by means of an air lift. Excess sludge for filter pressing could be removed either from tank D or tank 6. The rectangular settling tank (tank 8, Fig. 15) was used at times as the main settling tank in place of tank D, and was remodelled several times to obtain intensified results.

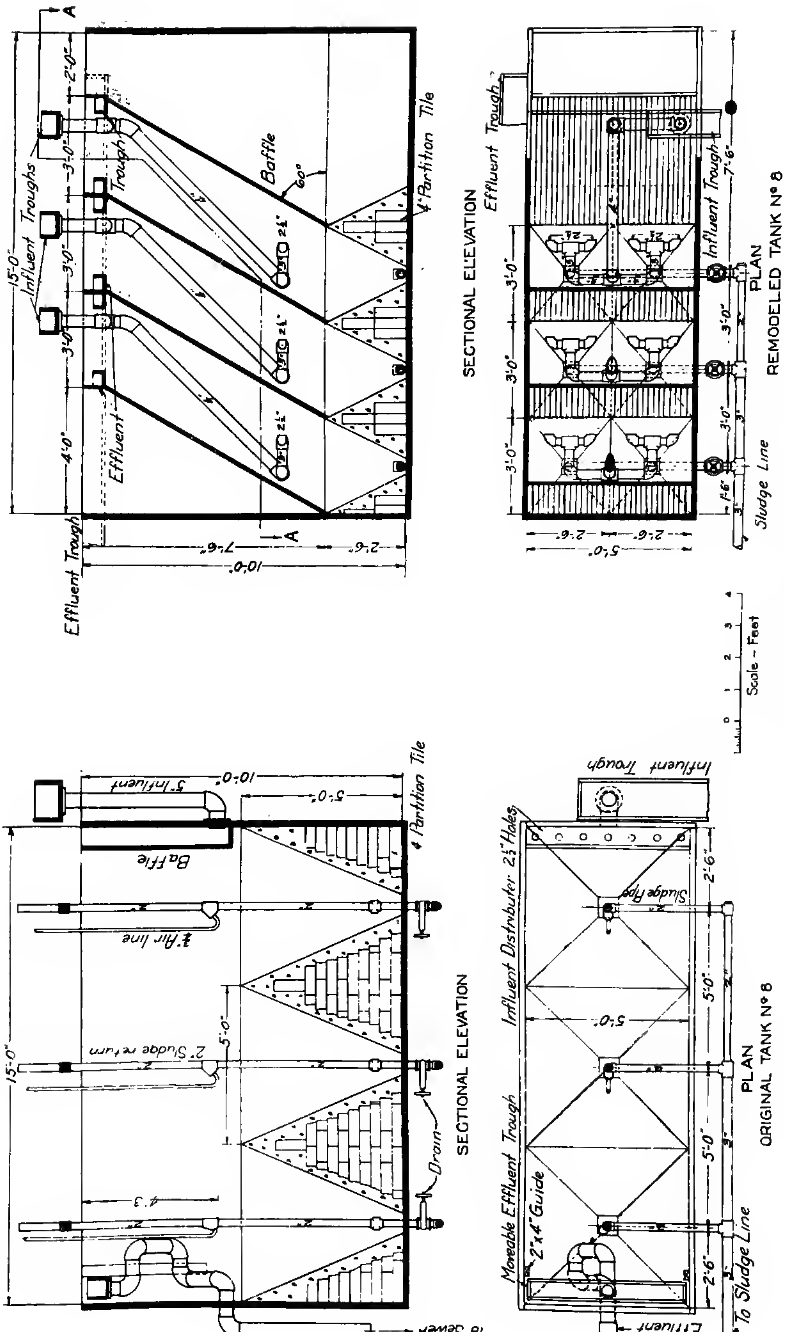


**Fig. 15. Horizontal Settling Tank.**

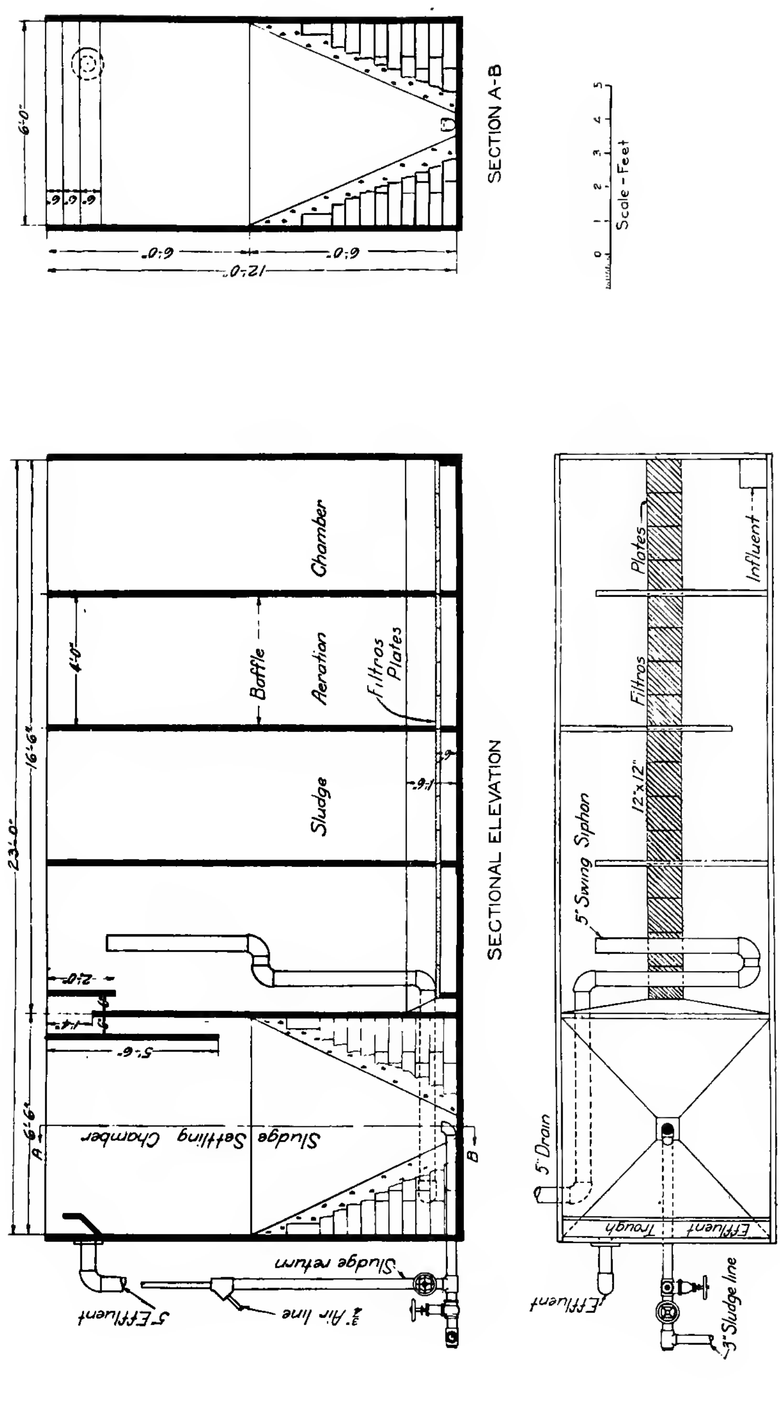


**Fig. 16. Aeration and Settling Tank.**

## CHAPTER III.

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## CRUDE SEWAGE.

SAMPLING. Samples of crude sewage were taken after passing through the grit chamber, following the 1914 report, in which the error in sampling was shown relatively of greater magnitude than the difference between the crude sewage and the grit chamber effluent. Samples were collected every hour and combined into a day composite from 8 a. m. to 10 p. m. inclusive, during 1914 and in January, 1915. Night samples were collected during this period from 11 p. m. to 7 a. m. inclusive. Tests made in the fall of 1914 indicated that the true strength of the day sewage would be more nearly represented if the 10 p. m. sample were included in the night sample. Accordingly, after February 1, 1915, the day samples were composited from 8 a. m. to 9. p. m. inclusive, and the night samples from 10 p. m. to 7 a. m. The 24 hour average was rated according to the length of the sampling period. On Sunday all samples were combined into one 24 hour composite.

YEARLY ANALYSES. The results of analyses of crude sewage by months are given in Tables 3 and 4. Only a few determinations were made on the crude sewage, sufficient to check the concentration. A few additional tests were made on the screened sewage, the influent to the activated sludge aeration tanks. The influent to the Imhoff tank and sprinkling filter was not screened.

The results of these averages are not entirely consistent, as some determinations show an increase, while others are decreased. Taken as a whole, however, the analyses indicate that the sewage was strongest in 1917.

## TABLE 3

ANALYSES OF CRUDE SEWAGE (GRIT CHAMBER EFFLUENT)
DAY SEWAGE, NOT INCLUDING SUNDAY

(8 a. m. to 10 p. m. in 1914. 8 a. m. to 9 p. m. in 1915, 1916, 1917)
Results in Parts per Million

| Month | Total Suspended Solids | | | | Volatile Suspended Solids | | | | Fixed Suspended Solids | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1914 | 1915 | 1916 | 1917 | 1914 | 1915 | 1916 | 1917 | 1914 | 1915 | 1916 | 1917 |
| Jan. | 498 | 411 | 401 | 429 | 411 | ..... | 319 | 342 | 87 | ..... | 82 | 87 |
| Feb. | 481 | 397 | 343 | 390 | 388 | ..... | 295 | 328 | 93 | ..... | 48 | 62 |
| Mar. | 464 | 382 | 343 | 506 | 380 | ..... | 280 | 422 | 84 | ..... | 63 | 84 |
| April | 356 | 406 | 287 | 367 | 291 | ..... | 220 | 302 | 65 | ..... | 67 | 65 |
| May | 395 | 335 | 281 | 350 | ..... | ..... | 222 | 289 | ..... | ..... | 59 | 61 |
| June | 381 | 375 | 324 | 399 | ..... | 302 | 267 | 322 | ..... | 73 | 57 | 77 |
| July | 363 | 360 | 321 | 349 | ..... | 288 | 266 | 271 | ..... | 72 | 55 | 78 |
| Aug. | 350 | 309 | 305 | 434 | ..... | 258 | 240 | 361 | ..... | 51 | 65 | 73 |
| Sept. | 410 | 332 | 367 | 506 | ..... | 252 | 296 | 427 | ..... | 80 | 71 | 79 |
| Oct. | 394 | 325 | 483 | 356 | ..... | 285 | 282 | 282 | ..... | 40 | 100 | 74 |
| Nov. | 417 | 369 | 381 | 401 | ..... | 312 | 214 | 338 | ..... | 57 | 67 | 63 |
| Dec. | 469 | 396 | 460 | 407 | ..... | 342 | 287 | 325 | ..... | 54 | 73 | 82 |
| Average | 415 | 366 | 358 | 408 | (367) | (291) | 291 | 334 | (82) | (61) | 67 | 74 |

| Month | Oxygen Consumed | | | | Fats | | | | Biochemical Oxygen Consumption | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1914 | 1915 | 1916 | 1917 | 1914 | 1915 | 1916 | 1917 | 1914 | 1915 | 1916 | 1917 |
| Jan. | ..... | ..... | 261 | 232 | ..... | 183 | 138 | 184 | ..... | 1162 | 1104 | 1099 |
| Feb. | ..... | ..... | 248 | 217 | ..... | 175 | 144 | 170 | ..... | 1068 | 1013 | 1241 |
| Mar. | ..... | ..... | 253 | 242 | ..... | 161 | 80 | 174 | ..... | 1022 | 1242 | 1000 |
| April | ..... | ..... | 228 | 194 | ..... | 142 | 82 | 116 | ..... | 1045 | 959 | 884 |
| May | ..... | 150 | 200 | 161 | ..... | 179 | 118 | 191 | ..... | 976 | 1035 | 971 |
| June | ..... | 157 | 269 | 165 | ..... | 138 | 126 | 138 | ..... | 993 | 944 | 795 |
| July | ..... | 177 | 257 | 151 | ..... | 156 | ..... | 127 | ..... | 1065 | 1038 | 984 |
| August | ..... | 164 | 168 | 178 | ..... | 96 | 146 | 166 | ..... | 856 | 1477 | 834 |
| Sept. | ..... | 165 | 195 | 174 | ..... | 113 | 133 | 116 | ..... | 810 | 973 | 841 |
| Oct. | ..... | 195 | 244 | 142 | ..... | 104 | 126 | 100 | ..... | 985 | 1086 | 867 |
| Nov. | ..... | 238 | 257 | 166 | ..... | 100 | 132 | 151 | ..... | 1148 | 1298 | 971 |
| Dec. | ..... | 265 | 234 | 156 | ..... | 92 | 122 | 146 | ..... | 1182 | 1246 | 1031 |
| Average | ..... | 190 | 218 | 181 | ..... | 137 | 122 | 148 | ..... | 1026 | 1118 | 960 |

## TABLE 4

ANALYSES OF CRUDE SEWAGE (GRIT CHAMBER EFFLUENT)
NIGHT SEWAGE, NOT INCLUDING SUNDAY

(11 p. m. to 7 a. m. in 1914. 10 p. m. to 7 a. m. in 1915, 16, 17.)
Results in Parts per Million

| Month | Total Suspended Solids | | | | Fats | | |
|---|---|---|---|---|---|---|---|
| | 1914 | 1915 | 1916 | 1917 | 1915 | 1916 | 1917 |
| Jan. | 115 | 98 | 202 | 160 | 51 | 70 | 59 |
| Feb. | 85 | 116 | 82 | 117 | 62 | 52 | 69 |
| March | 89 | 93 | 165 | 211 | 47 | 49 | 73 |
| April | 73 | 133 | 129 | 120 | 65 | 30 | 42 |
| May | 90 | 83 | 118 | 200 | 87 | 34 | 122 |
| June | 114 | 100 | 109 | ..... | 34 | 122 | 84 |
| July | 93 | 131 | 101 | 158 | 49 | 56 | 39 |
| Aug. | 92 | 135 | 171 | 231 | 39 | 75 | 67 |
| Sept. | 94 | 104 | 200 | 184 | 40 | 72 | 104 |
| Oct. | 113 | 102 | 241 | 176 | 52 | 58 | 77 |
| Nov. | 84 | 97 | 171 | 255 | 45 | 73 | 91 |
| Dec. | 115 | 128 | 176 | 313 | 25 | 76 | 134 |
| Average | 96 | 110 | 155 | 193 | 41 | 64 | 72 |

**TABLE 4—Continued**

DAY AND NIGHT WEIGHTED AVERAGE
SUNDAY, 24 HOURS
Results in Parts per Million

| Months | Day and Night Weighted Average | | | | | | | Sunday, 24 Hrs. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total Suspended Solids | | | | Fats | | | Total Suspended Solids | | |
| | 1914 | 1915 | 1916 | 1917 | 1915 | 1916 | 1917 | 1915 | 1916 | 1917 |
| Jan. | 357 | 294 | 318 | 317 | 133 | 110 | 132 | 198 | 180 | 199 |
| Feb. | 332 | 279 | 234 | 276 | 128 | 106 | 128 | 313 | 96 | 92 |
| March | 323 | 260 | 269 | 383 | 114 | 67 | 132 | 84 | 132 | 99 |
| April | 350 | 294 | 221 | 264 | 110 | 60 | 85 | 116 | 66 | 103 |
| May | 311 | 230 | 213 | 288 | 141 | 83 | 162 | 94 | 76 | 222 |
| June | 282 | 260 | 236 | 373 | 95 | 124 | 116 | 106 | 52 | 113 |
| July | 262 | 264 | 229 | 265 | 111 | 166 | 90 | 134 | 92 | 140 |
| Aug. | 253 | 237 | 249 | 349 | 72 | 116 | 125 | 80 | 118 | 105 |
| Sept. | 244 | 237 | 297 | 351 | 83 | 108 | 111 | 75 | 114 | 120 |
| Oct. | 289 | 233 | 382 | 281 | 82 | 98 | 90 | 119 | 207 | 231 |
| Nov. | 291 | 257 | 293 | 240 | 77 | 99 | 111 | 133 | 243 | 286 |
| Dec. | 336 | 284 | 342 | 367 | 64 | 103 | 141 | 156 | 267 | 159 |
| Average | 294 | 261 | 274 | 321 | 101 | 103 | 119 | 134 | 137 | 156 |

The monthly fluctuations, as in 1914, show a decided increase in strength in the winter months when the kill is greatest in Packingtown.

ADDITIONAL DETERMINATIONS. Complete analyses were not made on the crude sewage. To approximate the strength of the sewage from other tests, the following results average all determinations during 1913.

AVERAGE OF 1913 RESULTS

| Determination | P. P. M. |
|---|---|
| Ammonia Nitrogen | 22. |
| Total Organic Nitrogen | 79. |
| Chlorine | 1,100. |
| Alkalinity | 291. |
| Nitrate Nitrogen | 3.04 |
| Nitrite Nitrogen | 0.49 |

This indicates that most of the nitrogen is present in organic form, the ammonia nitrogen being a lower proportion of the total than is found in most domestic sewages. The freshness of the sewage probably accounts for the low ratio of ammonia to organic nitrogen.

WEIGHTED AVERAGE STRENGTH OF SEWAGE. All averages of the strength of the sewage have been based on a uniform rate of flow throughout the entire 24 hours, equal proportions being collected at hourly intervals. The volume of discharge, how-

ever, varies widely during 24 hours. In the fall of 1914 the true weighted average strength of the sewage was investigated. Samples were taken from the outlet of the grit chamber for one week, covering 2 hour periods made up of equal portions collected at 15 minute intervals. Unfortunately the weir at the sewer outlet had previously been destroyed, so that no direct comparison with the variations in the flow were possible. The week day flows for four weeks in September and October, 1913, when records were available, were therefore selected, as an essentially dry period. Slight rains occurred on two days while sampling was in progress. The average flow and suspended matter by periods is indicated in Table 5. The measurements of discharge were made on the even hour.

Table 5 shows that the average strength of the sewage for the entire 24 hours, weighted according to variations in flow, is nearly 20 per cent in excess of the average based on uniform flow. The variations between uniform and weighted averages for the "day" and "night" sewage are comparatively insignificant. The "day" sewage in this case does not include the 10 p. m. sample included in the routine tests. With an approximate correction for this additional sample, the relative difference is very slight. The average figures for the sewage strength obtained to date should be increased by about 20 per cent to give an average, weighted according to flow. The "day" and "night" averages, however, are substantially correct.

The suspended matter determinations for individual days are given in Table 6, with the assumed discharge. Compared with the average results for the week obtained on the routine samples,—384 p. p. m. for the day sewage, 65 p. p. m. for the night and 264 p. p. m. for the 24 hour,—the check is close particularly as the sampling periods are not exactly coincident. The 10 p. m. collection should apparently be included in the night sample.

## TABLE 5

COMPARISON OF SEWER DISCHARGE AND SUSPENDED MATTER BY PERIODS

| Time From | Time To | Discharge Cu. Ft. per Sec. | Ratio of Flow to Avg. for 24 Hr. | Suspended Matter Parts per Million |
|---|---|---|---|---|
| 7:45 a. m | 9:30 a. m. | 31.5 | 1.22 | 573 |
| 9:45 a. m. | 11:30 a. m. | 36.9 | 1.42 | 446 |
| 11:45 a. m. | 1:30 p. m. | 36.6 | 1.41 | 388 |
| 1:45 p. m. | 3:30 p. m. | 34.5 | 1.33 | 415 |
| 3·45 p m. | 5:30 p. m. | 32.2 | 1.24 | 474 |
| 5:45 p. m. | 7:30 p. m. | 28.8 | 1.22 | 345 |
| 7:45 p. m. | 9:30 p. m. | 23.2 | 0.90 | 161 |
| 9:45 p. m. | 11:30 p. m. | 18.7 | 0.72 | 133 |
| 11:45 p. m. | 1:30 a. m. | 17.7 | 0.68 | 72 |
| 1:45 a. m. | 3:30 a. m. | 16.4 | 0.63 | 67 |
| 3:45 a. m. | 5:30 a. m. | 16.3 | 0.63 | 75 |
| 5:45 a. m. | 7:30 a. m. | 17.6 | 0.68 | 151 |
| AVERAGE | | | | |
| 24 Hours | | 25.9 | 1.00 | 275 |
| 7:45 a. m. to 9:30 p. m. | | 32.0 | 1.23 | 401 |
| 9:45 p. m. to 7:30 a. m. | | 17.3 | 0.67 | 100 |
| WEIGHTED AVERAGE | | | | |
| 24 Hours | | ....... | ....... | 325 |
| 7:45 a. m. to 9:30 p. m. | | ....... | ....... | 412 |
| 9:45 p. m. to 7:30 a m. | | ....... | ....... | 101 |
| PERCENT INCREASE OVER STRAIGHT AVERAGE | | | | |
| 24 Hours | | ....... | ....... | 18 |
| 7:45 a. m. to 9:30 p. m. | | ....... | ....... | 3 |
| 9:45 p. m. to 7:30 a. m. | | ....... | ....... | 1 |

## TABLE 6

HOURLY VARIATIONS IN SUSPENDED MATTER

Oct. 26 to Nov. 1, 1914

Results in Parts per Million

| Time From | Time To | Mon. | Tues. | Wed. | Thurs. | Fri. | Sat. | Weighted Avg. | Uniform Avg. |
|---|---|---|---|---|---|---|---|---|---|
| 7:45 a. m. | 9:30 a. m. | 590 | 518 | 776 | 300 | 456 | 796 | 573 | ....... |
| 9:45 a. m. | 11:30 a. m. | 320 | 364 | 452 | 604 | 372 | 564 | 446 | ....... |
| 11:45 a. m. | 1:30 p. m. | 568 | 344 | 316 | 460 | 364 | 276 | 388 | ....... |
| 1:45 p. m. | 3:30 p. m. | 480 | 508 | 400 | 520 | 228 | 452 | 415 | ....... |
| 3:45 p. m. | 5:30 p. m. | 464 | 352 | 404 | 576 | 616 | 432 | 474 | ....... |
| 5:45 p. m. | 7:30 p. m. | 298 | 464 | 352 | 384 | 332 | 238 | 345 | ....... |
| 7:45 p. m. | 9:30 p. m. | 125 | 172 | 172 | 184 | 146 | 164 | 161 | ....... |
| 9:45 p. m. | 11:30 p. m. | 101 | 192 | 176 | 114 | 90 | 122 | 133 | ....... |
| 11:45 p. m. | 1:30 a. m. | 71 | 62 | 78 | 74 | 39 | 108 | 72 | ....... |
| 1:45 a. m. | 3:30 a. m. | 75 | 44 | 58 | 65 | 42 | 116 | 67 | ....... |
| 3:45 a. m. | 5:30 a. m. | 40 | 68 | 70 | 107 | 38 | 124 | 75 | ....... |
| 5:45 a. m. | 7:30 a. m. | 134 | 156 | 140 | 230 | 190 | 54 | 151 | ....... |
| AVERAGE | | | | | | | | | |
| 24 Hours | | 272 | 262 | 283 | 302 | 218 | 287 | 275 | 264 |
| 7:45 a. m. to 9:30 p. m. | | 406 | 375 | 410 | 433 | 359 | 417 | 401 | 384 |
| 9:45 p. m. to 7:30 a. m. | | 84 | 104 | 104 | 118 | 78 | 105 | 101 | 65 |

SOLVENT FOR FAT DETERMINATION. In December, 1917, a comparison was made of solvents for the extraction of fats in sewage from the stockyards and in screenings. Ethyl ether and petroleum ether were used. The extraction was made by several washings of the dry residue. Both acidified and non-acidified samples were used.

In all cases, the ethyl ether extraction gave results from 1.5 to 3.0 times as great as the petroleum ether extraction. Although ethyl ether is commonly accepted as having greater solvent action than petroleum ether, the excess found in these tests is unusual. The content of true fats is most nearly approximated by extraction in a Soxhlet extractor with petroleum ether for 5 to 12 hours. Ethyl ether dissolves lime, soaps and gummy residues more freely than petroleum ether. An extraction made with the former solvent may include these with true fats.

These observations indicate that the true fat content of stockyards wastes may be lower than indicated by the average analyses reported. The recoverable fats are certainly lower.

**TABLE 7**
COMPARISON OF ETHER SOLUBLE CONTENT USING ETHYL ETHER AND PETROLEUM ETHER

| Date | Source | Ether Soluble Content Parts per Million | | | | Ratio of Ethyl Ether Soluble / Petroleum Ether Soluble | |
|---|---|---|---|---|---|---|---|
| | | Ethyl Ether | | Petroleum Ether | | | |
| | | Non-acid | Acid | Non-acid | Acid | Non-acid | Acid |
| 1917 | STOCKYARDS TESTING STATION | | | | | | |
| Dec. | Imhoff Tank, Day | 57 | 110 | 27 | 62 | 2.11 | 1.77 |
| Dec. | Night | 58 | 61 | 28 | 30 | 2.07 | 2.03 |
| Dec. | Grit, Day | 94 | 146 | 28 | 88 | 3.35 | 1.66 |
| Dec. | Night | 91 | 134 | 37 | 96 | 2.46 | 1.40 |
| Dec. 31 to Jan. 5 | Screenings | 66600 | 91200 | 24800 | 53200 | 2.68 | 1.71 |
| 1918 | | | | | | | |
| Jan. 9 to 12 | Screenings | 63400 | 107200 | 43200 | 64400 | 1.47 | 1.67 |
| 1917 | BOYD, LUNHAM & CO. | | | | | | |
| Dec. 24 to 27 | Screenings | 231000 | 246400 | 179600 | 205800 | 1.29 | 1.20 |
| Dec. 28 to 31 | Screenings | 221200 | 286400 | 154000 | 177700 | 1.43 | 1.61 |
| 1918 | 39th ST. PUMPING STATION | | | | | | |
| Jan. 8 | Domestic Sewage | 50 | 40 | 22 | 20 | 2.27 | 2.00 |
| Jan. 23 | | 63 | ......... | 43 | ......... | 1.47 | ......... |
| Feb. 13 | | 20 | 34 | 14 | 18 | 1.43 | 1.89 |

METHOD OF ANALYSIS

*SEWAGE.* 250 cc. of sewage is evaporated to about dryness on hot plate, and then taken to dryness on steam bath. Acid samples are acidified before evaporation with sulphuric acid (1:3) until acid to methyl orange, usually 0.3 to 0.5 cc. required . The dry residue is then extracted with ether on steam bath until the ether from 2 successive extractions is colorless. About 3-4 cc. ether used for each extraction, and usually 6-7 extractions are required. The ether extract is evaporated to dryness on steam bath to constant weight, and the residue is calculated as ether soluble.

*SCREENINGS OR SLUDGE.* 0.5 gram dry sample extracted with ether as above until 2 successive extracts are colorless. Uusually 10 to 12 extractions are required. Extract is then treated as above

*PETROLEUM ETHER.* Boiling point 40° to 60° C.

*ETHYL ETHER.* U. S. P. 1910, anaesthesia ether containing about 2% alcohol

# CHAPTER IV.

## IMHOFF TANK.

GENERAL. The Imhoff tank was operated from the starting of the testing station (September 16, 1912) until March 6, 1918. The tank was a radial downward and upward flow type until March 9, 1914. On March 19, 1914, the remodeled tank went into service as a horizontal flow tank. The results obtained up to September 2, 1914, are summarized in the Report on Industrial Wastes from the Stockyards and Packingtown, October, 1914. The present report contains only the records secured since the remodelling of the tank in March, 1914. The operating schedule is shown in Table 8.

ANALYTICAL RESULTS. Monthly averages for suspended matter in the effluent for the day, night and 24-hour samples are shown in Tables 9 and 10, while the monthly averages for other constituents are shown in Tables 22, 23 and 24 in Chapter V. The averages by detention periods are shown in Table 11. Sunday samples are not included.

### TABLE 8

IMHOFF TANK (TANK E)
Operation Schedule

| From | To | Operation Schedule | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rate Gals. Daily | De-tention Period Hrs. | Mean Velocity | | | |
| | | | | Ft. per Hr. | | Min. per Sec. | |
| | | | | Down | Up | Down | Up |
| Vertical Flow | | | | | | | |
| Sept. 16, '12 | Nov. 2, '12 | 27,400 | 2.0 | 8.7 | 3.8 | 0.74 | 0.32 |
| Nov. 2, '12 | Mar. 1, '13 | 18,200 | 3.0 | 5.8 | 2.5 | 0.49 | 0.21 |
| Mar. 1, '13 | May 15, '13 | 13,700 | 4.0 | 4.4 | 1.9 | 0.37 | 0.16 |
| May 15, '13 | Oct. 1, '13 | 27,400 | 2.0 | 8.7 | 3.8 | 0.74 | 0.32 |
| Oct. 1, '13 | Feb. 10, '14 | 36,400 | 1.5 | 11.6 | 5.0 | 0.99 | 0.44 |
| Feb. 10, '14 | Mar. 9, '14 | 27,400 | 2.0 | 8.7 | 3.8 | 0.74 | 0.32 |
| Horizontal Flow | | | | | | | |
| Mar. 19, '14 | June 1, '14 | 15,200 | 1.9 | 9.2* | ........ | 0.79* | ........ |
| June 1, '14 | Sept. 2, '14 | 9,950 | 2.9 | 6.0 | ........ | 0.52 | ........ |
| Sept. 2, '14 | Dec. 2, '14 | 14,250 | 2.0 | 8.7 | ........ | 0.75 | ........ |
| Dec. 2, '14 | Feb. 1, '15 | 19,200 | 1.5 | 11.6 | ........ | 1.00 | ........ |
| Feb. 1, '15 | July 2, '15 | 9,600 | 3.0 | 5.8 | ........ | 0.50 | ........ |
| July 2, '15 | Mar. 6, '18 | 20,000 | 1.4 | 12.1 | ........ | 1.00 | ........ |

*Horizontal Velocities

## TABLE 9

### IMHOFF TANK (TANK E)

Reduction in Suspended Matter
Day Sewage (Sundays Omitted)

| | Suspended Matter—Parts per Million | | | | | | Percent Reduction | | | Detention Period Hours |
|---|---|---|---|---|---|---|---|---|---|---|
| | Influent | | | Effluent | | | | | | |
| | Total | Volatile | Fixed | Total | Volatile | Fixed | Total | Volatile | Fixed | |
| 1914 | | | | | | | | | | |
| Mar. 19 to 31 | 553 | 461 | 92 | 225 | 194 | 30 | 59 | 58 | 67 | 1.9 |
| April | 356 | 291 | 65 | 137 | 111 | 26 | 62 | 62 | 60 | 1.9 |
| May | 395 | ...... | ...... | 156 | ...... | ...... | 61 | .... | .... | 1.9 |
| June | 381 | ...... | ...... | 112 | ...... | ...... | 71 | .... | .... | 2.9 |
| July | 363 | ...... | ...... | 107 | ...... | ...... | 71 | .... | .... | 2.9 |
| August | 350 | ...... | ...... | 83 | ...... | ...... | 76 | .... | .... | 2.9 |
| September | 410 | ...... | ...... | 118 | ...... | ...... | 71 | .... | .... | 2.0 |
| October | 394 | ...... | ...... | 136 | ...... | ...... | 65 | .... | .... | 2.0 |
| November | 417 | ...... | ...... | 155 | ...... | ...... | 63 | .... | .... | 2.0 |
| December | 469 | ...... | ...... | 227 | 182 | 45 | 52 | .... | .... | 1.5 |
| 1915 | | | | | | | | | | |
| January | 411 | ...... | ...... | 219 | 193 | 26 | 47 | .... | .... | 1.5 |
| February | 397 | ...... | ...... | 183 | 154 | 29 | 54 | .... | .... | 3.0 |
| March | 382 | ...... | ...... | 179 | 149 | 30 | 53 | .... | .... | 3.0 |
| April | 406 | ...... | ...... | 178 | 141 | 37 | 56 | .... | .... | 3.0 |
| May | 335 | ...... | ...... | 146 | 127 | 19 | 56 | .... | .... | 3.0 |
| June | 375 | 302 | 73 | 140 | 118 | 22 | 63 | 61 | 70 | 3.0 |
| July | 360 | 288 | 72 | 181 | 145 | 36 | 50 | 50 | 50 | 1.4 |
| August | 309 | 258 | 51 | 137 | 109 | 28 | 56 | 58 | 45 | 1.4 |
| September | 332 | 252 | 80 | 158 | 114 | 44 | 52 | 55 | 45 | 1.4 |
| October | 325 | 285 | 40 | 146 | 128 | 18 | 55 | 55 | 55 | 1.4 |
| November | 369 | 312 | 57 | 177 | 145 | 32 | 52 | 54 | 44 | 1.4 |
| December | 396 | 342 | 54 | 209 | 171 | 38 | 47 | 50 | 30 | 1.4 |
| 1916 | | | | | | | | | | |
| January | 401 | 319 | 82 | 293 | 226 | 67 | 27 | 29 | 18 | 1.4 |
| February | 343 | 295 | 48 | 264 | 205 | 59 | 23 | 31 | —23 | 1.4 |
| March | 343 | 280 | 63 | 230 | 188 | 42 | 33 | 33 | 33 | 1.4 |
| April | 287 | 220 | 67 | 202 | 164 | 38 | 30 | 25 | 43 | 1.4 |
| May | 281 | 222 | 59 | 152 | 113 | 39 | 46 | 49 | 34 | 1.4 |
| June | 324 | 267 | 57 | 144 | 113 | 31 | 56 | 58 | 46 | 1.4 |
| July | 321 | 266 | 55 | 165 | 122 | 43 | 49 | 54 | 22 | 1.4 |
| August | 305 | 240 | 65 | 148 | 114 | 34 | 51 | 52 | 48 | 1.4 |
| September | 367 | 296 | 71 | 168 | 139 | 29 | 54 | 53 | 59 | 1.4 |
| October | 483 | 383 | 100 | 226 | 173 | 53 | 53 | 55 | 47 | 1.4 |
| November | 381 | 314 | 67 | 193 | 152 | 41 | 49 | 52 | 39 | 1.4 |
| December | 460 | 387 | 73 | 263 | 224 | 39 | 43 | 42 | 47 | 1.4 |
| 1917 | | | | | | | | | | |
| January | 429 | 342 | 64 | 340 | 260 | 80 | 21 | 24 | —25 | 1.4 |
| February | 390 | 328 | 62 | 256 | 212 | 44 | 34 | 35 | 29 | 1.4 |
| March | 506 | 422 | 84 | 273 | 234 | 39 | 46 | 45 | 54 | 1.4 |
| April | 367 | 302 | 65 | 238 | 196 | 42 | 35 | 35 | 35 | 1.4 |
| May | 350 | 289 | 61 | 213 | 179 | 34 | 39 | 38 | 44 | 1.4 |
| June | 399 | 322 | 77 | 237 | 200 | 37 | 41 | 38 | 52 | 1.4 |
| July | 349 | 272 | 77 | 189 | 132 | 57 | 46 | 51 | 26 | 1.4 |
| August | 434 | 361 | 73 | 145 | 118 | 27 | 67 | 67 | 63 | 1.4 |
| September | 506 | 427 | 79 | 152 | 111 | 41 | 70 | 74 | 48 | 1.4 |
| October | 356 | 282 | 74 | 180 | 138 | 42 | 49 | 51 | 43 | 1.4 |
| November | 401 | 338 | 63 | 168 | 132 | 36 | 58 | 61 | 43 | 1.4 |
| December | 407 | 325 | 82 | 254 | 209 | 55 | 38 | 36 | 45 | 1.4 |
| 1918 | | | | | | | | | | |
| January | 311 | 245 | 66 | 271 | 222 | 49 | 13 | 9 | 26 | 1.4 |
| February | 519 | 449 | 70 | 295 | 273 | 22 | 43 | 39 | 69 | 1.4 |

**TABLE 11**

IMHOFF TANK

Analyses of Effluent

| Detention Period Hours | Parts per Million | | | | | | | | Ether Sol-uble | Bio. Oxygen Demand |
|---|---|---|---|---|---|---|---|---|---|---|
| | Nitrogen as | | | | Oxy-Cons. | Suspended Matter | | | | |
| | Org. | Free Amm. | Nitrite | Nitrate | | Tot. | Vol. | Fixed | | |
| | | | | | DAY SEWAGE | | | | | |
| 1.4 to 1.5 | 51 | 28 | 0.22 | 1.66 | 158 | 209 | 168 | 41 | 83 | 730 |
| 1.9 to 2.0 | .... | .... | ...... | ...... | ..... | 146 | 132 | 27 | .... | ..... |
| 2.9 to 3.0 | 57 | 26 | 0.16 | 2.53 | 143 | 141 | ..... | .... | 98 | 750 |
| | | | | | NIGHT SEWAGE | | | | | |
| 1.4 to 1.5 | 30 | 21 | 0.11 | 0.94 | 77 | 107 | ..... | .... | 52 | 730 |
| 1.9 to 2.0 | .... | .... | ..... | ..... | .... | 63 | ..... | .... | .... | ..... |
| 2.9 to 3.0 | 30 | 23 | 0.13 | 1.80 | 70 | 72 | ..... | .... | 52 | 750 |
| | | | | | 24-HOUR SEWAGE | | | | | |
| 1.4 to 1.5 | 42 | 25 | 0.17 | 1.36 | 123 | 167 | ..... | .... | 73 | ..... |
| 1.9 to 2.0 | .... | .... | ...... | ...... | ..... | 117 | ..... | .... | .... | ..... |
| 2.9 to 3.0 | 46 | 25 | 0.15 | 2.23 | 112 | 113 | ..... | .... | 79 | 540 |

REDUCTION OF SUSPENDED MATTER. Tables 9 and 10 show the reduction in suspended matter by monthly averages for the day, night and 24-hour samples, while Table 12 shows the results summarized by detention periods, including the Sunday sewage, which resembles the night flow. The Sunday sewage is omitted in the other averages. In general, greater reductions were obtained with the horizontal flow tank than with the original installation, except for the 1.4 to 1.5 hour detention period, where the average removal was smaller. This, however, was probably due to the fact that during the last two years of operation, when the tank was running on a 1.4 hour detention period, less attention was paid to efficient operation and control than earlier. Leakage around the baffles and gas vents had developed to a considerable extent, because of the temporary character of the baffle construction.

REDUCTION OF OXYGEN CONSUMED, FATS, AND BIOLOGIC OXYGEN DEMAND. Reductions obtained in oxygen consumed, ether soluble matter and biologic oxygen demand, are shown in Table 13, arranged by detention periods for such periods as these determinations were made.

## TABLE 12

IMHOFF TANK

Reduction of Suspended Matter by Detention Periods

| Detention Period Hours | Suspended Matter in Parts per Million | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Influent | | | Effluent | | | Percent Reduction | | |
| | Tot. | Vol. | Fixed | Tot. | Vol. | Fixed | Tot. | Vol. | Fixed |
| DAY SEWAGE | | | | | | | | | |
| 1.4 to 1.5 | 382 | 310 | 67 | 209 | 168 | 41 | 45 | 46 | 39 |
| 1.9 to 2.0 | 404 | 335 | 72 | 146 | 132 | 27 | 64 | 61 | 62 |
| 2.9 to 3.0 | 374 | ...... | ...... | 141 | ...... | .... | 62 | .... | .... |
| NIGHT SEWAGE | | | | | | | | | |
| 1.4 to 1.5 | 166 | ...... | .... | 107 | ...... | .... | 32 | .... | .... |
| 1.9 to 2.0 | 92 | ...... | .... | 63 | ...... | .... | 30 | .... | .... |
| 2.9 to 3.0 | 103 | ...... | .... | 72 | ...... | .... | 30 | .... | .... |
| 24-HOUR SEWAGE | | | | | | | | | |
| 1.4 to 1.5 | 289 | ...... | .... | 167 | ...... | .... | 42 | .... | .... |
| 1.9 to 2.0 | 283 | ...... | .... | 117 | ...... | .... | 59 | .... | .... |
| 2.9 to 3.0 | 265 | ...... | .... | 113 | ...... | .... | 57 | .... | .... |
| SUNDAY SEWAGE | | | | | | | | | |
| 1.4 to 1.5 | 140 | ...... | .... | 80 | .... | .... | 43 | .... | .... |
| 2.9 to 3.0 | 140 | ...... | .... | 80 | .... | .... | 43 | .... | .... |

## TABLE 13

IMHOFF TANK

Reduction in Oxygen Consumed, Ether Soluble Matter and Biologic Oxygen Demand

| Detention Period Hours | Parts per Million | | | | | | Percent Reduction | | |
|---|---|---|---|---|---|---|---|---|---|
| | Influent | | | Effluent | | | | | |
| | Oxy. Cons. | Ether Sol. | Bio. Oxy. Demand | Oxy. Cons. | Ether Sol. | Bio. Oxy. Demand | Oxy. Cons. | Ether Sol. | Bio. Oxy. Demand |
| DAY SEWAGE | | | | | | | | | |
| 1.4 to 1.5 | 197 | 132 | 1030 | 154 | 83 | 730 | 22 | 37 | 29 |
| 2.9 to 3.0 | 154 | 159 | 1020 | 112 | 98 | 750 | 27 | 38 | 27 |
| NIGHT SEWAGE | | | | | | | | | |
| 1.4 to 1.5 | ...... | 65 | ...... | ...... | 52 | ...... | .... | 20 | .... |
| 2.9 to 3.0 | ...... | 54 | 270 | ...... | 52 | 250 | .... | 12 | 7 |
| 24-HOUR SEWAGE | | | | | | | | | |
| 1.4 to 1.5 | ...... | 100 | ...... | ...... | 73 | ...... | .... | 27 | .... |
| 2.9 to 3.0 | ...... | 118 | 700 | ...... | 79 | 540 | .... | 33 | 23 |

## TABLE 14

IMHOFF TANK (TANK E)
Record of Sludge and Scum Accumulation

| Date | Cubic Yards per Million Gallons | | | | | Cubic Yards Sludge Removed | Detention Period Hours |
|---|---|---|---|---|---|---|---|
| | Sludge Since Last Measurement | Scum Since Last Cleaning | Since Start | | | | |
| | | | Sludge | Scum | Total | | |
| 1912 | | | | | | | |
| Sept. 16 | Tank Started Operation | | | | | | |
| 1914 | | | | | | | |
| Mar. 9 | ...... | ...... | 6.5 | 1.3 | 7.8 | ...... | ...... |
| | Tank Shut Down Mar. 9-18 for Remodelling | | | | | | |
| 27 | 12.8 | ...... | 6.5 | ...... | ...... | ...... | 1.9 |
| April 4 | 10.5 | ...... | 6.6 | ...... | ...... | ...... | 1.9 |
| 13 | 6.9 | 0.6 | 6.5 | 1.4 | 7.9 | 6.2 | 1.9 |
| May 1 | 17.3 | ...... | 6.8 | ...... | ...... | ...... | 1.9 |
| 13 | 6.4 | ...... | 6.8 | ...... | ...... | ...... | 1.9 |
| 26 | 6.2 | ...... | 6.8 | ...... | ...... | ...... | 1.9 |
| June 1 | 3.8 | 0.3 | 6.7 | 1.3 | 8.0 | ...... | 1.9 |
| July 6 | 1.3 | ...... | 6.6 | ...... | ...... | ...... | 2.9 |
| 22 | 7.1 | ...... | 6.6 | ...... | ...... | 4.6 | 2.9 |
| Aug. 2 | 19.1 | ...... | 6.7 | ...... | ...... | ...... | 2.9 |
| 24 | 12.8 | ...... | 6.8 | ...... | ...... | ...... | 2.9 |
| Oct. 20 | 2.5 | ...... | 6.6 | ...... | ...... | 9.4 | 2.0 |
| Nov. 9 | 10.9 | ...... | 6.7 | ...... | ...... | ...... | 2.0 |
| Dec. 2 | 8.0 | 0.3 | 6.7 | 1.2 | 7.9 | ...... | 2.0 |
| 1915 | | | | | | | |
| Jan. 15 | 6.7 | ...... | 6.7 | ...... | ...... | ...... | 1.5 |
| Feb. 5 | 12.2 | 1.0 | 6.8 | 1.2 | 8.0 | 12.2 | 1.5 |
| 25 | 5.2 | ...... | 6.8 | ...... | ...... | ...... | 3.0 |
| Mar. 3 | 6.9 | ...... | 6.8 | ...... | ...... | 0.4 | 3.0 |
| April 29 | 12.8 | 0.9 | 7.0 | 1.2 | 8.2 | ...... | 3.0 |
| June 16 | 3.1 | ...... | 6.9 | ...... | ...... | 8.5 | 3.0 |
| July 2 | 33.4 | ...... | 7.1 | ...... | ...... | ...... | 3.0 |
| Aug. 25 | 6.5 | 0.3 | 7.1 | 1.1 | 8.2 | 5.5 | 1.4 |
| Sept. 30 | 9.1 | ...... | 7.1 | ...... | ...... | 5.7 | 1.4 |
| Nov. 3 | 11.0 | 0.1 | 7.3 | 1.0 | 8.3 | 3.8 | 1.4 |
| Dec. 6 | 13.3 | ...... | 7.4 | ...... | ...... | ...... | 1.4 |
| 1916 | | | | | | | |
| Jan. 23 | ...... | 0.3 | ...... | 1.0 | ...... | ...... | 1.4 |
| 29 | ...... | 3.4 | ...... | 1.0 | ...... | ...... | 1.4 |
| Feb. 19 | ...... | 3.5 | ...... | 1.0 | ...... | ...... | 1.4 |
| Mar. 8 | 5.1 | 1.8 | 7.2 | 1.0 | 8.2 | ...... | 1.4 |

SLUDGE RESULTS. The ebullition of gas from the sludge chamber was continuous during the entire life of the tank. Although generally inoffensive, the odor of hydrogen sulphide was sometimes noted. Scum was almost continuously present on the surface of the gas vents.

Sludge measurements were made at monthly intervals, as a rule, or whenever it became necessary to withdraw sludge, the depth of sludge being obtained by lowering a closed bottle at the end of a graduated rod into the tank, withdrawing the stopper, lifting the sample thus obtained for examination, and repeating the operation at various depths until the sludge line was closely established. The rate of accumulation between individual measurements varied considerably because of seasonal differences in strength of the sewage, violence of gas ebullition and moisture content of the sludge. The rate of accumulation between individual measurements is shown in Table 14, while the average rates summarized by different detention periods are given in Table 15. These figures are brought up to March 8, 1916 only.

**TABLE 15**

IMHOFF TANK (TANK E)
Sludge and Scum Accumulation by Detention Periods

| Detention Period Hours | Cubic Yards per Million Gallons | | |
|---|---|---|---|
| | Sludge | Scum | Total |
| 1.4 to 1.5 | 7.6 | 0.9 | 8.5 |
| 1.9 to 2.0 | 7.5 | 0.3 | 7.8 |
| 2.9 to 3.0 | 10.3 | 0.5 | 10.8 |

## TABLE 16

IMHOFF TANK (TANK E)
Analyses of Bottom Sludge

| Date | Specific Gravity | Percent Moisture | Percentage—Dry Weight | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | Nitrogen | Volatile | Fixed | Ether Soluble | | |
| | | | | | | Non-acid | Acid | |
| 1914 | | | | | | | | |
| Mar. 20 | 1.04 | 90.7 | .... | .... | .... | .... | .... | |
| 27 | 1.01 | 90.0 | .... | .... | .... | 6.6 | .... | Top |
| 27 | 1.01 | 92.9 | .... | .... | .... | 7.0 | .... | Bottom |
| April 13 | 1.02 | 94.9 | 2.56 | 66 | 34 | 5.8 | .... | Top |
| 13 | 1.02 | 94.6 | 2.56 | 68 | 32 | 6.3 | .... | Bottom |
| May 1 | 1.03 | 93.8 | .... | .... | .... | .... | .... | |
| 13 | 1.03 | 94.1 | .... | .... | .... | .... | .... | |
| 26 | 1.03 | 93.2 | .... | .... | .... | .... | .... | |
| June 1 | 1.03 | 92.7 | .... | .... | .... | .... | .... | |
| July 6 | 1.03 | 93.8 | .... | 57 | 43 | .... | .... | |
| July 22 | 1.03 | 92.1 | .... | .... | .... | .... | .... | |
| Sept. 2 | 1.03 | 92.0 | 2.16 | 58 | 42 | 5.4 | .... | Bottom |
| 24 | 1.04 | 92.4 | .... | .... | .... | .... | .... | |
| Oct. 20 | 1.04 | 91.8 | .... | .... | .... | .... | .... | |
| Nov. 9 | 1.01 | 96.2 | 2.56 | 64 | 36 | 6.7 | .... | |
| 1915 | | | | | | | | |
| Jan. 1 | 1.04 | 91.0 | .... | .... | .... | .... | .... | |
| Feb. 5 | 1.03 | 91.7 | 2.96 | 72 | 28 | 8.2 | 16.0 | |
| April 25 | 1.03 | 91.3 | .... | .... | .... | .... | .... | |
| 29 | 1.01 | 96.6 | 2.56 | 72 | 28 | 14.4 | 30.9 | |
| July 2 | 1.04 | 93.7 | .... | .... | .... | .... | .... | |
| Aug. 25 | 1.01 | 93.7 | 3.68 | 64 | 36 | 8.0 | 9.8 | |
| Sept. 30 | 1.03 | 94.8 | .... | .... | .... | .... | .... | |
| Nov 3 | 1.03 | 95.0 | .... | .... | .... | .... | .... | |
| Dec. 10 | 1.03 | 95.9 | 2 88 | 66 | 34 | 7.8 | 8.4 | |

## TABLE 17

IMHOFF TANK (TANK E)
Analyses of Scum from Gas Vents

| Date | Specific Gravity | Percent Moisture | Percentage—Dry Weight | | | | |
|---|---|---|---|---|---|---|---|
| | | | Nitrogen | Volatile | Fixed | Ether Soluble | |
| | | | | | | Non-Acid | Acid |
| 1914 | | | | | | | |
| Mar. 27 | 0.99 | 86.2 | .... | .... | .... | 27.8 | .... |
| April 13 | 1.03 | 79.9 | .... | .... | .... | .... | .... |
| June 1 | 1.03 | 80.0 | .... | .... | .... | .... | .... |
| Dec. 2 | 1.02 | 81.8 | .... | .... | .... | .... | .... |
| 1915 | | | | | | | |
| Feb. 5 | 1.04 | 79.5 | 3.36 | 76 | 24 | 15.2 | 28.7 |
| Aug. 25 | .... | 82.9 | 3.04 | 72 | 28 | 13.5 | 19.8 |
| Nov. 3 | 1.03 | 85.4 | 3.52 | .... | .... | 13.4 | 18.9 |
| 1916 | | | | | | | |
| April 28 | 1.03 | 79.9 | 2.40 | 78 | 22 | 14.2 | 35.4 |

## TABLE 18

IMHOFF TANK (TANK E)

Analyses of Scum from Settling Chamber

| Date | Specific Gravity | Percent Moisture | Percentage—Dry Weight | | | | |
|---|---|---|---|---|---|---|---|
| | | | Nitrogen | Volatile | Fixed | Ether Soluble | |
| | | | | | | Non-Acid | Acid |
| 1915 | | | | | | | |
| Jan. 15 | 1.03 | 86.6 | 2.96 | 83 | 17 | 9.0 | 29.2 |
| Feb. 5 | 1.03 | 90.0 | 2.96 | 81 | 19 | 7.3 | 13.5 |
| April 28 | 1.02 | 81.0 | 2.24 | 73 | 27 | 19.2 | 45.5 |
| July 20 | 1.02 | 80.0 | 2.08 | 71 | 29 | 13.4 | 35.3 |
| Aug. 2 | 2.02 | 85.6 | 2.56 | 68 | 32 | 12.0 | 31.2 |
| 24 | 1.02 | 83.8 | 2.16 | 73 | 27 | 15.2 | 33.7 |
| Sept. 13 | 1.03 | 81.9 | ........ | .... | .... | 11.9 | 25.3 |
| 20 | 1.03 | 78.8 | ........ | .... | .... | ........ | ........ |
| Oct. 11 | 1.02 | 73.8 | ........ | 79 | 21 | 22.2 | 49.5 |
| 15 | 1.02 | 80.9 | ........ | 80 | 20 | 24.8 | 46.4 |
| Nov. 3 | 1.02 | 85.8 | ........ | .... | .... | 22.9 | 40.7 |
| 13 | 1.03 | 83.2 | ........ | .... | .... | 23.1 | 40.6 |
| Dec. 1 | 1.01 | 82.5 | ........ | .... | .... | 19.6 | 34.8 |

## TABLE 19

IMHOFF TANK (TANK E)

Record of Sludge Drying

| Date | Removed From Tank | | | Removable From Bed | | | | |
|---|---|---|---|---|---|---|---|---|
| | Depth on Bed Feet | Specific Gravity | Percent Moisture | Days Elapsed | Depth on Bed Feet | Specific Gravity | Percent Moisture | Percent Reduction Volume |
| 1914 | | | | | | | | |
| April 13 | 0.54 | 1.03 | 92.4 | 4 | 0.30 | 1.09 | 78.5 | 45 |
| July 22 | 0.78 | 1 03 | 91.8 | 6 | 0.50 | 1.12 | 72.6 | 36 |
| July 22 | 0.87 | ...... | 91.4 | 7 | 0.47 | 1.03 | 84.3 | 46 |
| Oct. 20 | 0.92 | 1.04 | 90.5 | 7 | 0.53 | 1.08 | 7.76 | 42 |
| 1915 | | | | | | | | |
| Aug. 25 | 0.88 | 1.03 | 92.6 | 6 | 0.42 | 1.04 | 77.2 | 52 |
| Aug. 25 | 1.48 | 1.03 | 90.9 | 6 | 0.77 | 1.04 | 79.2 | 48 |

In addition to the accumulation of scum on the gas vents, a thin greasy scum persisted on the surface of the settling chamber. This was retained by a scum board near the outlet weir and accumulated at the average rate of about 0.4 cu. yd. per million gal. of sewage.

Samples of sludge and scum were collected frequently for analysis (Tables 16, 17 and 18). In general the moisture content of the sludge was uniformly higher than that noted in most Imhoff tank installations, possibly because of the shallow depth of the tank, and the violence of gas formation in the sludge chamber. The gas vent scum was usually dry enough to remove with a fork and was appreciably higher in volatile matter than the sludge. The nitrogen content in both sludge and scums was much lower than in the activated sludge. The ether soluble content was high in all,

particularly so in the scum from the settling chamber. A considerable increase was noted in the acidified samples over those extracted without acidification.

Sludge drying was tried on underdrained beds of graded gravel overlaid by sand (Table 19). In general the sludge drawn from the tank was uniformly black or very dark gray in color, flowed freely and drained readily on the beds, like typical Imhoff sludge. Beside the regular drying experiments, two tests were made on drying Imhoff sludge on covered beds during winter conditions. An undrained bed, 3 ft. by 3 ft. 6 in. was used, filled with 6 in. of graded stone overlaid with 2 in. of torpedo sand. An air space, 2½ to 3½ in. in width, surrounded the bed, which was protected with a high wooden cover. The sludge drained readily, and although somewhat wetter when removed than that dried under summer conditions, was nevertheless readily spadeable. A thin crust of ice formed on the surface of the first sample but none on the second. Although not made under very severe conditions, the tests indicate that under suitable conditions of protection, drying could be carried on during the winter months (Table 20).

**TABLE 20**

TESTS OF DRYING IMHOFF SLUDGE UNDER COVER

| Date on Bed, 1915 | February 25 | March 3 |
|---|---|---|
| Removable—Days Elapsed | 4. | 5. |
| Sludge Depth in Feet—Initial | 1.00 | 0.87 |
| Sludge Depth in Feet—Final | 0.70 | 0.57 |
| Percent Reduction—Volume | 30. | 34. |
| Percent Moisture—Initial | 91.3 | 92.8 |
| Percent Moisture—Final | 78.4 | 78.2 |
| Air Temperature, Fahr.— | | |
| Inside Bed Average | 30. | 32. |
| Inside Lowest | 30. | 30. |
| Air Average | 30. | 32. |
| Air Lowest | 21. | 24. |

# CHAPTER V.

## SPRINKLING FILTER AND SECONDARY SETTLING BASIN.

GENERAL. Operation of the sprinkling filter was continuous from Sept. 22, 1913, to Dec. 9, 1917, except for occasional brief shutdowns for repairs. The gross area of the filter was 0.005 acre, but for the purpose of figuring rates the net area was taken as 0.00393 acre, based on a circle 14 ft. 9 in. diameter because the nozzle throws a circular spray. The operating schedule is given by months, together with influent and effluent temperatures (Table 21).

In general the filter was operated week days and was rested from Sunday morning to Monday morning. During the winter, however, it was frequently necessary to omit the resting period to avoid freezing in the influent piping and under-drains. The gross rate is the rate at which sewage was actually applied to the filter when in operation. In figuring the net yield, all short resting periods as well as other brief shutdowns, are included, and deduction has only been made for protracted shutdowns noted under the column headed "Remarks."

ANALYSES. Analyses of the influent and effluent of the filter for all constituents except suspended matter and biologic oxygen demand, averaged by months for the day, night and 24-hour samples are shown in Tables 22, 23 and 24. Long time averages for the various net rates of application are shown in Table 25, together with the percentage reduction. About two-thirds of the organic nitrogen was removed by the filter while the reduction of oxygen consumed and fats was somewhat less. Monthly averages for suspended matter and biological oxygen demand are shown in Tables 26 to 30 inclusive.

REDUCTION OF SUSPENDED MATTER. Tables 26, 27 and 28 show the monthly average reduction in suspended matter for the day, night and 24-hour samples. The effluent was consistently high in suspended matter at all times, the lowest content occuring as a rule during the warm months of the summer and early fall. No distinct seasonal period of unloading has been observed, although at intervals during the winter and spring, the suspended matter in the effluent exceeded that in the influent. The

## TABLE 21

SPRINKLING FILTER

Monthly Operation Schedule

| Date | Temp. Degrees Fahr. | | Aver. Hrs. Operated | Million Gals. per Acre Daily | | Remarks |
|---|---|---|---|---|---|---|
| | Inf. | Eff. | Daily | Gross Rate | Net Yield | |
| 1913 | | | | | | |
| Sept. | 84 | 57 | 23.2 | 0.844 | 0.816 | Started Sept. 22 |
| Oct. | 76 | 56 | 20.8 | 0.844 | 0.733 | |
| Nov. | 71 | 51 | 19.9 | 0.844 | 0.700 | |
| Dec. | 69 | 47 | 20.9 | 0.902 | 0.782 | Shutdown Dec. 18 for Repairs |
| 1914 | | | | | | |
| Jan. | 64 | 44 | 22.2 | 0.941 | 0.900 | Started Jan. 3 |
| Feb. | 62 | 44 | 21.8 | 0.839 | 0.758 | |
| Mar. | 61 | 47 | 21.6 | 0.810 | 0.730 | Shut down Mar. 9-20 |
| April | 68 | 55 | 20.5 | 1.190 | 1.017 | |
| May | 73 | 64 | 19.7 | 1.186 | 0.978 | |
| June | 83 | 71 | 19.9 | 1.135 | 0.941 | |
| July | 91 | 78 | 18.8 | 1.238 | 1.012 | |
| Aug. | 91 | 78 | 19.8 | 1.438 | 1.188 | |
| Sept. | 85 | 76 | 20.7 | 1.760 | 1.509 | |
| Oct. | 81 | 69 | 19.9 | 1.500 | 1.244 | |
| Nov. | 70 | 52 | 17.5 | 1.185 | 0.862 | Shut down Nov. 1-11 for Rest |
| Dec. | 64 | 50 | 23.0 | 1.185 | 1.136 | |
| 1915 | | | | | | |
| Jan. | 63 | 50 | 23.2 | 1.185 | 1.150 | |
| Feb. | 58 | 47 | 22.0 | 0.880 | 0.830 | |
| Mar. | 63 | 47 | 20.4 | 0.905 | 0.750 | |
| April | 73 | 58 | 19.6 | 1.149 | 0.920 | |
| May | 72 | 61 | 19.5 | 1.168 | 0.952 | |
| June | 77 | 68 | 20.5 | 1.168 | 0.995 | |
| July | 84 | 77 | 19.9 | 1.168 | 0.970 | |
| Aug. | 84 | 72 | 19.7 | 1.168 | 0.915 | Shut down Aug. 3-9 for Rest |
| Sept. | 84 | 76 | 20.6 | 1.168 | 1.000 | Shut down Sept. 22-30 for Repairs |
| Oct. | 78 | 66 | 20.4 | 1.168 | 0.994 | Shut down Oct. 1-4 for Repairs |
| Nov. | 72 | 58 | 22.0 | 0.681 | 0.624 | |
| Dec. | 68 | 52 | 23.8 | 0.681 | 0.677 | |
| 1916 | | | | | | |
| Jan. | 65 | 48 | 23.1 | 0.681 | 0.660 | Shut down Jan. 17-24 and 29-31 frozen |
| Feb. | 64 | 49 | 23.5 | 0.681 | 0.667 | Shut down Feb. 1-16, frozen |
| Mar. | ...... | ...... | 22.4+ | 0.681 | 0.635+ | |
| April | 66 | 53 | 19.6+ | 0.681 | 0.556+ | |
| May | 73 | 60 | 19.9+ | 0.681 | 0.562+ | |
| June | 79 | 64 | 20.7 | 0.681 | 0.586 | |
| July | 87 | 77 | 19.4 | 0.681 | 0.548 | |
| Aug. | 90 | 77 | 20.8 | 0.681 | 0.589 | Shut down Aug. 18 |
| Sept. | ...... | ...... | ...... | ...... | ...... | Not Operated |
| Oct. | 77 | 58 | 20.1 | 0.681 | 0.569 | Started Oct. 4 |
| Nov. | 78 | 53 | 20.0 | 0.681 | 0.566 | |
| Dec. | 68 | 46 | 16.9+ | 0.681 | 0.478 | |
| 1917 | | | | | | |
| Jan. | 65 | 46 | ...... | 0.681 | ...... | Records Incomplete |
| Feb. | ...... | ...... | ...... | 0.681 | ...... | Records Incomplete |
| Mar. | 65 | 54 | ...... | 0.681 | ...... | Records Incomplete |
| April | 65 | 55 | 19.9 | 0.681 | 0.562 | |
| May | 69 | 55 | 20.1 | 0.681 | 0.569 | |
| June | 72 | 64 | 20.7 | 0.681 | 0.586 | |
| July | 81 | 71 | 19.4 | 0.681 | 0.547 | |
| Aug. | 83 | 72 | 20.9 | 0.681 | 0.593 | |
| Sept. | 80 | 67 | 19.6 | 0.681 | 0.556 | Shut down Sept. 29 |
| Oct. | 73 | 49 | 18.7 | 0.681 | 0.530 | Started Oct. 25 |
| Nov. | 70 | 51 | 20.3 | 0.681 | 0.573 | |
| Dec. | 67 | 49 | 21.0 | 0.681 | 0.594 | Shut down Dec.9 |

high mineral content of the effluent during October, 1913, is unquestionably due to the washing out of the stone dust from the filtering material.

DISSOLVED OXYGEN, RELATIVE STABILITY AND BIOCHEMICAL OXYGEN DEMAND. Samples for the determination of dissolved oxygen and relative stabilities were taken 4

# TABLE 25

## SPRINKLING FILTER

Analyses of Influent and Effluent and Percentage Reductions by Periods

| Date | Approximate Net Yield M. G. D. per A. | Parts per Million: Influent, Nitrogen as Total Org. | Influent, Nitrogen as Free Amm. | Influent, Nitrogen as $NO_2$ | Influent, Nitrogen as [illegible] | Influent, Oxy. Cons. | Influent, Ether Sol. | Effluent, Nitrogen as Total Org. | Effluent, Nitrogen as Free Amm. | Effluent, Nitrogen as $NO_2$ | Effluent, Nitrogen as $NO_3$ | Effluent, Oxy. Cons. | Effluent, Ether Sol. | Percent Reduction: Nitrogen as Total Org. | Nitrogen as Free Amm. | Oxy. Cons. | Ether Sol. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DAY SEWAGE** | | | | | | | | | | | | | | | | | |
| Sept. 22, '13 to Feb. 1, '14 | 0.786 | 62 | 31 | .31 | [illegible] | 177 | | 21 | 26 | 1.24 | 15.5 | 57 | | 66 | 16 | 68 | |
| April 1, '14 to Aug. 1, '14 | 0.987 | | | | | | | 13 | 14 | 4.20 | 18.9 | | | | | | |
| Aug. 1, '14 to Nov. 1, '14 | 1.313 | | | | | | | 16 | 16 | 2.00 | 13.7 | | | | | | |
| Dec. 1, '14 to Nov. 1, '15 | 0.965 | 57 | 29 | .18 | [illegible]4 | 151 | 90 | 20 | 27 | 1.93 | 13.0 | 74 | 52 | 65 | 67 | 51 | 42 |
| Nov. 1, '15 to Dec. 8, '17 | 0.583 | 49 | 28 | .23 | [illegible].58 | 160 | 85 | 20 | 15 | 1.95 | 22.6 | 71 | 39 | 59 | 46 | 56 | 54 |
| **NIGHT SEWAGE** | | | | | | | | | | | | | | | | | |
| Sept. 22, '13 to Feb. 1, '14 | 0.786 | | | | | | | | | | | | | | | | |
| April 1, '14 to Aug. 1, '14 | 0.987 | | | | | | | 8 | 8 | 2.70 | 15.4 | | | | | | |
| Aug. 1, '14 to Nov. 1, '14 | 1.313 | | | | | | | 16 | 17 | 1.00 | 10.1 | | | | | | |
| Dec. 1, '14 to Nov. 1, '15 | 0.965 | 30 | 24 | .12 | 1.38 | 71 | 49 | 14 | 20 | 1.19 | 11.8 | 52 | 39 | 53 | 17 | 27 | 20 |
| Nov. 1, '15 to Dec. 8, '17 | 0.583 | 28 | 21 | .11 | 0.91 | 77 | 54 | 14 | 13 | 1.35 | 17.5 | 58 | 35 | 50 | 38 | 25 | 35 |
| **24-HOUR SEWAGE** | | | | | | | | | | | | | | | | | |
| Sept. 22, '13 to Feb. 1, '14 | 0.786 | | | | | | | | | | | | | | | | |
| April 1, '14 to Aug. 1, '14 | 0.987 | | | | | | | 10 | 12 | 3.60 | 17.1 | | | | | | |
| Aug. 1, '14 to Nov. 1, '14 | 1.313 | | | | | | | 16 | 15 | 1.75 | 12.9 | | | | | | |
| Dec. 1, '14 to Nov. 1, '15 | 0.965 | 46 | 27 | .15 | 1.90 | 119 | 73 | 18 | 24 | 1.64 | 12.6 | 65 | 49 | 61 | 11 | 45 | 33 |
| Nov. 1, '15 to Dec. 8, '17 | 0.583 | 40 | 25 | .18 | 1.3 | 124 | 72 | 17 | 14 | 1.66 | 19.3 | 65 | 37 | 58 | 44 | 48 | 49 |

## TABLE 26

SPRINKLING FILTER

Reduction in Suspended Matter

Day Sewage—Monthly Averages

| Month | Suspended Matter—Parts per Million | | | | | | Percent Reduction | | |
|---|---|---|---|---|---|---|---|---|---|
| | Influent | | | Effluent | | | | | |
| | Total | Vol. | Fixed | Total | Vol. | Fixed | Total | Vol. | Fixed |
| 1913 | | | | | | | | | |
| September 22-30 | 258 | 210 | 48 | 98 | 66 | 32 | 62 | 69 | 33 |
| October | 248 | 184 | 64 | 321 | 146 | 175 | 29* | 21 | 174* |
| November | 262 | 205 | 57 | 144 | 99 | 45 | 45 | 52 | 21 |
| December 1-18 | 276 | 231 | 45 | 135 | 103 | 32 | 51 | 55 | 29 |
| 1914 | | | | | | | | | |
| Jan. 3-31 | 228 | 180 | 48 | 109 | 71 | 38 | 52 | 61 | 21 |
| February | 193 | 154 | 39 | 122 | 88 | 34 | 37 | 43 | 13 |
| Mar. 1-9; 20-31 | 173 | 147 | 26 | 117 | 80 | 37 | 32 | 46 | 42* |
| April | 137 | 111 | 26 | 208 | 148 | 60 | 52* | 33* | 131* |
| May | 156 | ...... | ...... | 140 | ...... | ...... | 10 | ...... | ...... |
| June | 112 | ...... | ...... | 99 | ...... | ...... | 12 | ...... | ...... |
| July | 107 | ...... | ...... | 81 | ...... | ...... | 24 | ...... | ...... |
| August | 83 | ...... | ...... | 73 | ...... | ...... | 12 | ...... | ...... |
| September | 118 | ...... | ...... | 113 | ...... | ...... | 4 | ...... | ...... |
| October | 136 | ...... | ...... | 110 | ...... | ...... | 19 | ...... | ...... |
| November | 155 | ...... | ...... | 102 | ...... | ...... | 34 | ...... | ...... |
| December | 227 | 182 | 45 | 154 | 118 | 36 | 32 | 35 | 20 |
| 1915 | | | | | | | | | |
| January | 219 | 193 | 26 | 179 | 147 | 32 | 18 | 24 | 23* |
| February | 183 | 154 | 29 | 197 | 135 | 62 | 8* | 12 | 114* |
| March | 179 | 149 | 30 | ...... | ...... | ...... | ...... | ...... | ...... |
| April | 178 | 141 | 37 | ...... | ...... | ...... | ...... | ...... | ...... |
| May | 146 | 127 | 19 | 121 | 101 | 20 | 17 | 20 | 5* |
| June | 140 | 118 | 22 | 184 | 117 | 67 | 31* | 1 | 204* |
| July | 181 | 145 | 36 | 124 | 85 | 39 | 32 | 41 | 8* |
| August | 137 | 109 | 28 | 113 | 54 | 59 | 18 | 50 | 110* |
| September | 158 | 114 | 44 | 73 | 44 | 29 | 54 | 61 | 34 |
| October | 146 | 128 | 18 | 72 | 52 | 20 | 51 | 59 | 11* |
| November | 177 | 145 | 32 | 155 | 102 | 53 | 12 | 30 | 65* |
| December | 209 | 171 | 38 | 242 | 168 | 74 | 16* | 2 | 95* |
| 1916 | | | | | | | | | |
| January | 293 | 226 | 67 | [illegible] | 231 | 113 | 17* | 2* | 69* |
| February | 264 | 205 | 59 | 162 | 132 | 30 | 39 | 36 | 49 |
| March | 230 | 188 | 42 | 166 | 125 | 41 | 28 | 33 | 2 |
| April | 202 | 164 | 38 | 176 | 125 | 51 | 13 | 24 | 34* |
| May | 152 | 113 | 39 | 192 | 136 | 56 | 26* | 20* | 44* |
| June | 144 | 113 | 31 | 129 | 78 | 51 | 11 | 31 | 64* |
| July | 165 | 122 | 43 | 105 | 58 | 47 | 36 | 52 | 9* |
| August | 148 | 114 | 34 | 94 | 45 | 49 | 37 | 60 | 44* |
| September | 168 | 139 | 29 | ...... | ...... | ...... | ...... | ...... | ...... |
| October | 226 | 173 | 53 | 129 | 73 | 56 | 43 | 58 | 6* |
| November | 193 | 152 | 41 | 229 | 150 | 79 | 18* | 1 | 93* |
| December | 263 | 224 | 39 | 277 | 176 | 101 | 5* | 21 | 159* |
| 1917 | | | | | | | | | |
| January | 340 | 260 | 80 | 360 | 160 | 200 | 6* | 38 | 150* |
| February | 256 | 212 | 44 | ...... | ...... | ...... | ...... | ...... | ...... |
| March | 273 | 234 | 39 | 372 | 216 | 156 | 36* | 7 | 300* |
| April | 238 | 196 | 42 | 280 | 138 | 142 | 18* | 30 | 238* |
| May | 213 | 179 | 34 | 285 | 172 | 113 | 34* | 4 | 232* |
| June | 237 | 200 | 37 | 160 | 88 | 72 | 33 | 56 | 94* |
| July | 189 | 132 | 57 | 131 | 52 | 79 | 31 | 61 | 39* |
| August | 145 | 118 | 27 | 93 | 58 | 35 | 36 | 51 | 29* |
| September | 152 | 111 | 41 | 87 | 54 | 33 | 43 | 51 | 20 |
| October | 180 | 138 | 42 | ...... | ...... | ...... | ...... | ...... | ...... |
| November | 168 | 132 | 36 | 126 | 75 | 51 | 25 | 43 | 42* |
| December | 254 | 209 | 45 | 352 | 224 | 128 | 39* | 7* | 184* |

*Denotes Increase

times daily at 3 a. m., 9 a. m., 3 p. m., and 9 p. m. The results, averaged by months, appear in Table 29. Dissolved oxygen was normally present in the effluent at all times, as shown by the monthly averages. Average stabilities approaching 100 were obtained during the warm summer months of the year, even with net rates ex-

## TABLE 27

SPRINKLING FILTER

Reduction in Suspended Matter

Night Sewage—Monthly Averages

| Month | Suspended Matter—Parts per Million | | | | | | Percent Reduction | | |
|---|---|---|---|---|---|---|---|---|---|
| | Influent | | | Effluent | | | | | |
| | Total | Vol. | Fixed | Total | Vol. | Fixed | Total | Vol. | Fixed |
| 1913 | | | | | | | | | |
| Sept. 22-30 | 88 | 74 | 14 | 233 | 128 | 105 | 165* | 73* | 650* |
| October | 84 | 63 | 21 | 318 | 136 | 182 | 279* | 116* | 767* |
| November | 98 | 69 | 29 | 137 | 88 | 49 | 40* | 28* | 69* |
| Dec. 1-18 | 95 | 66 | 29 | 105 | 72 | 33 | 10* | 9* | 14* |
| 1914 | | | | | | | | | |
| Jan. 3-31 | 86 | 63 | 23 | 63 | 44 | 19 | 27 | 30 | 17 |
| February | 52 | 39 | 13 | 69 | 52 | 17 | 33* | 33* | 31* |
| Mar. 1-9; 20-31 | 89 | 70 | 19 | 120 | 77 | 43 | 35* | 10* | 126* |
| April | 51 | 38 | 13 | 158 | 111 | 47 | 210* | 192* | 261* |
| May | 58 | ...... | ...... | 115 | ...... | ...... | 98* | ...... | ...... |
| June | 57 | ...... | ...... | 72 | ...... | ...... | 26* | ...... | ...... |
| July | 53 | ...... | ...... | 74 | ...... | ...... | 40* | ...... | ...... |
| August | 43 | ...... | ...... | 64 | ...... | ...... | 49* | ...... | ...... |
| September | 62 | ...... | ...... | 100 | ...... | ...... | 62* | ...... | ...... |
| October | 64 | ...... | ...... | 81 | ...... | ...... | 27* | ...... | ...... |
| November | 72 | ...... | ...... | 95 | ...... | ...... | 32* | ...... | ...... |
| December | 99 | 72 | 27 | 87 | 60 | 27 | 12 | 17 | 0 |
| 1915 | | | | | | | | | |
| January | 94 | 81 | 13 | 154 | 123 | 31 | 64* | 52* | 138* |
| February | 98 | 78 | 20 | 170 | 115 | 55 | 73* | 47* | 175* |
| March | 81 | 64 | 17 | ...... | ...... | ...... | ...... | ...... | ...... |
| April | 101 | 71 | 30 | ...... | ...... | ...... | ...... | ...... | ...... |
| May | 64 | 56 | 9 | 117 | 77 | 40 | 83* | 37* | 345* |
| June | 79 | 63 | 16 | 164 | 106 | 58 | 108* | 68* | 262* |
| July | 71 | 58 | 13 | 78 | 56 | 22 | 10* | 3 | 69* |
| August | 70 | 56 | 14 | 91 | 45 | 46 | 30* | 20 | 228* |
| September | 71 | 46 | 25 | 68 | 34 | 34 | 4 | 26 | 36* |
| October | 81 | 70 | 11 | 47 | 34 | 13 | 42 | 51 | 18* |
| November | 86 | 69 | 17 | 98 | 67 | 31 | 14* | 3 | 82* |
| December | 130 | 99 | 31 | 206 | 141 | 65 | 58* | 43* | 109* |
| 1916 | | | | | | | | | |
| January | 219 | 167 | 52 | 237 | 158 | 79 | 8* | 5 | 52* |
| February | 120 | 89 | 31 | 122 | 110 | 12 | 2* | 24* | 61 |
| March | 102 | 78 | 24 | 124 | 100 | 24 | 22* | 28* | 0 |
| April | 97 | 68 | 29 | 149 | 101 | 48 | 54* | 49* | 65* |
| May | 82 | 63 | 19 | 151 | 105 | 46 | 84* | 67* | 142* |
| June | 82 | 65 | 17 | 105 | 59 | 46 | 28* | 9 | 171* |
| July | 71 | 45 | 26 | 79 | 48 | 31 | 11* | 7* | 19* |
| August | 66 | 49 | 17 | 82 | 38 | 44 | 24* | 22 | 159* |
| September | 113 | 88 | 25 | ...... | ...... | ...... | ...... | ...... | ...... |
| October | 127 | 92 | 35 | 133 | 66 | 67 | 5* | 28 | 91* |
| November | 99 | 79 | 20 | 163 | 109 | 54 | 65* | 38* | 170* |
| December | 102 | 86 | 16 | 217 | 141 | 76 | 113* | 64* | 375* |
| 1917 | | | | | | | | | |
| January | 91 | 74 | 17 | 346 | 166 | 180 | 280* | 124* | 960* |
| February | 86 | 71 | 15 | ...... | ...... | ...... | ...... | ...... | ...... |
| March | 141 | 117 | 24 | 300 | ...... | ...... | 113* | ...... | ...... |
| April | 90 | 70 | 20 | 278 | 136 | 142 | 209* | 95* | 610* |
| May | 109 | 88 | 21 | 265 | 163 | 102 | 142* | 85* | 386* |
| June | 151 | 130 | 21 | 156 | 88 | 68 | 3* | 32 | 224* |
| July | 85 | 57 | 28 | 81 | 26 | 55 | 5 | 54 | 96* |
| August | 75 | 58 | 17 | 71 | 35 | 36 | 5 | 40 | 112* |
| September | 106 | 81 | 25 | 76 | 41 | 35 | 28 | 49 | 40* |
| October | 90 | 69 | 21 | ...... | ...... | ...... | ...... | ...... | ...... |
| November | 123 | 104 | 19 | 116 | 72 | 44 | 6 | 31 | 132* |
| December | 150 | 125 | 25 | 102 | 80 | 22 | 32 | 36 | 12 |

*Denotes Increase

ceeding one million gallons per acre daily, but in the winter the stability in general fell off markedly, although a very appreciable degree of purification was secured. During the last full winter of operation (1916-17), when the filter was operating at a comparatively low rate, high stabilities were maintained throughout the

## TABLE 28

### SPRINKLING FILTER

Reduction in Suspended Matter

Day and Night (24 Hours) Sewage Monthly Averages

| Month | Suspended Matter—Parts per Million | | | | | | Percent Reduction | | |
|---|---|---|---|---|---|---|---|---|---|
| | Influent | | | Effluent | | | | | |
| | Total | Vol. | Fixed | Total | Vol. | Fixed | Total | Vol. | Fixed |
| **1913** | | | | | | | | | |
| Sept. 22-30 | 197 | 163 | 34 | 148 | 89 | 59 | 25 | 45 | 74* |
| October | 196 | 144 | 45 | 319 | 142 | 177 | 63* | 1 | 293* |
| November | 204 | 158 | 46 | 147 | 99 | 48 | 28 | 37 | 4* |
| Dec. 1-18 | 210 | 171 | 39 | 124 | 91 | 33 | 41 | 47 | 15 |
| **1914** | | | | | | | | | |
| Jan. 3-13 | 164 | 127 | 37 | 90 | 59 | 31 | 45 | 54 | 16 |
| February | 141 | 111 | 30 | 104 | 75 | 29 | 26 | 32 | 3 |
| Mar. 1-9; 20-31 | 141 | 116 | 25 | 121 | 79 | 42 | 14 | 32 | 68* |
| April | 104 | 83 | 21 | 183 | 132 | 51 | 76* | 59* | 143* |
| May | 125 | ...... | ...... | 123 | ...... | ...... | 2 | ...... | ...... |
| June | 92 | ...... | ...... | 86 | ...... | ...... | 7 | ...... | ...... |
| July | 87 | ...... | ...... | 78 | ...... | ...... | 11 | ...... | ...... |
| Aug. | 68 | ...... | ...... | 70 | ...... | ...... | 3* | ...... | ...... |
| September | 97 | ...... | ...... | 108 | ...... | ...... | 11* | ...... | ...... |
| October | 109 | ...... | ...... | 100 | ...... | ...... | 8 | ...... | ...... |
| November | 126 | ...... | ...... | 100 | ...... | ...... | 21 | ...... | ...... |
| December | 179 | 141 | 38 | 126 | 95 | 31 | 30 | 33 | 18 |
| **1915** | | | | | | | | | |
| January | 172 | 151 | 21 | 170 | 138 | 32 | 1 | 9 | 52* |
| February | 146 | 120 | 26 | 194 | 131 | 63 | 33* | 9* | 142* |
| March | 138 | 114 | 24 | ...... | ...... | ...... | ...... | ...... | ...... |
| April | 146 | 112 | 34 | ...... | ...... | ...... | ...... | ...... | ...... |
| May | 112 | 97 | 15 | 119 | 90 | 29 | 7* | 7 | 93* |
| June | 115 | 95 | 20 | 176 | 112 | 64 | 53* | 18* | 220* |
| July | 135 | 109 | 26 | 105 | 73 | 32 | 22 | 33 | 23* |
| August | 109 | 87 | 22 | 104 | 50 | 54 | 5 | 43 | 145* |
| September | 122 | 86 | 36 | 71 | 40 | 31 | 42 | 53 | 14 |
| October | 119 | 104 | 15 | 62 | 45 | 17 | 48 | 57 | 13* |
| November | 139 | 113 | 26 | 131 | 87 | 44 | 6 | 23 | 69* |
| December | 176 | 141 | 35 | 227 | 157 | 70 | 29* | 11* | 100* |
| **1916** | | | | | | | | | |
| January | 262 | 201 | 61 | 299 | 200 | 99 | 14* | 0 | 62* |
| February | 204 | 157 | 47 | 146 | 123 | 23 | 28 | 22 | 51 |
| March | 177 | 142 | 35 | 148 | 114 | 34 | 16 | 20 | 3 |
| April | 158 | 124 | 34 | 165 | 114 | 51 | 4* | 8 | 50* |
| May | 123 | 92 | 31 | 175 | 125 | 51 | 42* | 36* | 64* |
| June | 118 | 93 | 25 | 119 | 70 | 49 | 1* | 25 | 96* |
| July | 126 | 90 | 36 | 94 | 54 | 40 | 25 | 40 | 11* |
| August | 114 | 87 | 27 | 89 | 42 | 47 | 22 | 52 | 74* |
| September | 145 | 118 | 27 | ...... | ...... | ...... | ...... | ...... | ...... |
| October | 185 | 139 | 46 | 130 | 70 | 60 | 30 | 50 | 30* |
| November | 153 | 121 | 32 | 197 | 132 | 65 | 29* | 9* | 103* |
| December | 196 | 167 | 29 | 251 | 161 | 90 | 28* | 4 | 210* |
| **1917** | | | | | | | | | |
| January | 236 | 185 | 51 | 354 | 162 | 192 | 50* | 12 | 276* |
| February | 185 | 154 | 31 | ...... | ...... | ...... | ...... | ...... | ...... |
| March | 218 | 185 | 33 | 342 | ...... | ...... | 57* | ...... | ...... |
| April | 176 | 143 | 33 | 279 | 137 | 142 | 58* | 4 | 331 |
| May | 170 | 141 | 29 | 277 | 168 | 109 | 63* | 19* | 276* |
| June | 201 | 171 | 30 | 158 | 88 | 70 | 22 | 49 | 133* |
| July | 140 | 95 | 45 | 110 | 41 | 69 | 21 | 57 | 53* |
| August | 115 | 93 | 22 | 84 | 49 | 35 | 27 | 47 | 59* |
| September | 133 | 99 | 34 | 82 | 48 | 34 | 38 | 52 | 0 |
| October | 142 | 109 | 33 | ...... | ...... | ...... | ...... | ...... | ...... |
| November | 149 | 119 | 30 | 122 | 74 | 48 | 18 | 38 | 60* |
| December | 210 | 174 | 36 | 248 | 164 | 84 | 18* | 6 | 133* |

*Denotes Increase

cold weather. Table 29 also shows the biologic oxygen demand for the day samples. These determinations were made for the most part by the saltpeter method on 2-day composites made up of samples collected every 2 hours, although at first they were made on individual samples, collected daily 2 or 3 days a week. Table 30

## TABLE 29

SPRINKLING FILTER

Biologic Oxygen Demand Dissolved Oxygen and Relative Stability

Monthly Averages

| Month | Net Yield M. C. D. per A. | Temp. Degrees Fahr. | Parts per Million: Bio. Oxygen Dem. Day | Parts per Million: Dissolved Oxygen 24-Hour | Relative Stability 24-Hour |
|---|---|---|---|---|---|
| 1913 | | | | | |
| Sept. 22-30 | 0.816 | 57 | ...... | 8.2 | .... |
| October | 0.733 | 56 | ...... | 6.2 | 64 |
| November | 0.700 | 51 | ...... | 6.2 | 70 |
| *Dec. | 0.782 | 47 | ...... | 6.4 | 74 |
| 1914 | | | | | |
| Jan. | 0.900 | 44 | *109 | 3.6 | 33 |
| Feb. | 0.758 | 44 | *92 | 4.8 | 71 |
| *Mar. | 0.730 | 47 | ...... | 4.6 | 82 |
| April | 1.017 | 55 | *75 | 3.4 | 63 |
| May | 0.978 | 64 | 68 | 3.4 | 92 |
| June | 0.941 | 71 | 43 | 5.1 | 94 |
| July | 1.012 | 78 | 52 | 5.2 | 96 |
| Aug. | 1.188 | 78 | *58 | 4.9 | 83 |
| September | 1.509 | 76 | 85 | ...... | .... |
| October | 1.244 | 69 | 103 | ...... | .... |
| *November | 0.862 | 52 | 183 | 4.2 | 21 |
| December | 1.136 | 50 | 203 | 3.5 | 26 |
| 1915 | | | | | |
| January | 1.150 | 50 | 230 | 2.8 | 18 |
| February | 0.830 | 47 | 241 | 3.5 | 29 |
| March | 0.750 | 47 | ...... | ...... | .... |
| April | 0.920 | 58 | ...... | ...... | .... |
| May | 0.952 | 61 | 248 | 2.1 | 70 |
| June | 0.995 | 68 | 249 | 3.1 | 73 |
| July | 0.970 | 77 | 153 | 2.3 | 40 |
| *August | 0.915 | 72 | 96 | 3.8 | 89 |
| *September | 1.000 | 76 | 87 | 2.9 | 75 |
| *October | 0.994 | 66 | 189 | 3.5 | 61 |
| November | 0.624 | 58 | 183 | 3.5 | 51 |
| December | 0.677 | 52 | 242 | 3.5 | 32 |
| 1916 | | | | | |
| *January | 0.660 | 48 | 232 | 3.1 | 24 |
| *February | 0.667 | 49 | ...... | 4.5 | 37 |
| March | 0.635+ | .... | 157 | 6.8 | 35 |
| April | 0.556+ | 53 | 122 | 4.0 | 83 |
| May | 0.562+ | 60 | 69 | 3.4 | 97 |
| June | 0.586 | 64 | 73 | 2.8 | 97 |
| July | 0.548 | 77 | 91 | 2.9 | 98 |
| *August | 0.589 | 77 | ...... | 3.7 | 98 |
| *October | 0.569 | 58 | ...... | 4.6 | 55 |
| November | 0.566 | 53 | 141 | 4.5 | 84 |
| *December | 0.478 | 46 | 145 | 4.7 | 76 |
| 1917 | | | | | |
| *January | .......... | 46 | 77 | 4.0 | 79 |
| *March | .......... | 54 | 104 | 1.8 | 50 |
| April | 0.562 | 55 | 129 | 3.2 | 71 |
| May | 0.569 | 55 | 83 | 4.2 | 95 |
| June | 0.586 | 64 | 38 | 4.5 | 97 |
| July | 0.547 | 71 | 114 | 3.7 | 96 |
| August | 0.593 | 72 | 57 | 3.7 | 89 |
| September | 0.556 | 67 | 15 | 4.5 | 93 |
| November | 0.573 | 51 | 64 | 5.0 | 88 |
| December 1-9 | 0.594 | 49 | ...... | 4.6 | 75 |

*Part of Month Only

shows the biologic oxygen demand by months for the crude day sewage, Imhoff tank effluent and effluent from the sprinkling filter together with the relative reductions effected by each of the two latter devices based on the initial demand of the crude sewage. Table 31 shows the same results summarized by net rates of application to the filter. Table 31 indicates that in general the reduction

## TABLE 30

SPRINKLING FILTER

Reduction in Biologic Oxygen Demand—Imhoff Tank and Sprinkling Filter

DAY SEWAGE    MONTHLY AVERAGES

| Month | Net Yield M G. D. per A. | Biologic Oxygen Demand Parts per Million | | | Percent Reduction | | |
|---|---|---|---|---|---|---|---|
| | | Grit Chamber | Imhoff Tank | Sprinkling Filter | Imhoff Tank | Sprinkling Filter | Total |
| 1914 | | | | | | | |
| Jan. 14-31 | 0.900 | 1010 | 790 | 109 | 21 | 68 | 89 |
| *February | 0.758 | 1030 | 760 | 92 | 26 | 65 | 91 |
| *April | 1.017 | 830 | 630 | 75 | 24 | 67 | 91 |
| May | 0.978 | 930 | 630 | 68 | 32 | 61 | 93 |
| June | 0.941 | 1020 | 530 | 43 | 48 | 48 | 96 |
| July | 1.012 | 1070 | 560 | 52 | 48 | 47 | 95 |
| *August | 1.188 | 1000 | 550 | 58 | 45 | 49 | 94 |
| September | 1.509 | 920 | 590 | 85 | 36 | 55 | 91 |
| October | 1.244 | 1010 | 590 | 103 | 42 | 48 | 90 |
| *November | 0.862 | 1040 | 660 | 183 | 37 | 45 | 82 |
| December | 1.186 | 1090 | 740 | 203 | 32 | 49 | 81 |
| 1915 | | | | | | | |
| January | 1.150 | 1160 | 880 | 230 | 24 | 56 | 80 |
| February | 0.830 | 1070 | 790 | 241 | 26 | 51 | 77 |
| May | 0.952 | 980 | 700 | 248 | 29 | 46 | 75 |
| June | 0.995 | 990 | 740 | 249 | 25 | 50 | 75 |
| July | 0.970 | 1070 | 740 | 153 | 31 | 55 | 86 |
| August | 0.915 | 860 | 630 | 96 | 27 | 62 | 89 |
| September | 1.000 | 810 | 580 | 87 | 28 | 61 | 89 |
| October | 0.994 | 990 | 630 | 189 | 36 | 45 | 81 |
| November | 0.624 | 1150 | 750 | 183 | 35 | 49 | 84 |
| December | 0.677 | 1180 | 730 | 242 | 38 | 42 | 80 |
| 1916 | | | | | | | |
| January | 0.660 | 1100 | 680 | 232 | 38 | 41 | 79 |
| February | 0.667 | 1010 | 570 | ...... | 44 | .... | .... |
| March | 0.635+ | 1240 | 800 | 157 | 36 | 51 | 87 |
| April | 0.556+ | 960 | 740 | 122 | 23 | 64 | 87 |
| May | 0.562+ | 1040 | 710 | 69 | 32 | 61 | 93 |
| June | 0.586 | 940 | 660 | 73 | 30 | 62 | 92 |
| July | 0.548 | 1040 | 700 | 91 | 33 | 58 | 91 |
| November | 0.566 | 1300 | 850 | 141 | 35 | 54 | 89 |
| December | 0.478 | 1260 | 890 | 145 | 29 | 59 | 88 |
| 1917 | | | | | | | |
| January | .......... | 1100 | 790 | 77 | 28 | 65 | 93 |
| February | .......... | 1240 | 760 | ...... | 39 | .... | .... |
| March | .......... | 980 | 740 | 104 | 25 | 64 | 89 |
| April | 0.562 | 880 | 720 | 129 | 18 | 67 | 85 |

*Part of Month Only

in biologic oxygen demand secured by preliminary settling amounted to between 30 and 40 percent on the strong day sewage, while a reduction of somewhat over 50 percent was accomplished in addition by the filter. The total reduction brought about by both devices was in the neighborhood of 90 percent. The residual amount of oxygen necessary for complete stability was largely and sometimes completely present during the summer months in the form of dissolved oxygen, nitrates and nitrites.

SECONDARY SETTLING BASIN. The removal of suspended matter for the day, night and 24 hour samples accomplished in the secondary settling basin, is shown in Table 32. In general the results accomplished in the tank of the Dortmund type were rather unsatisfactory as it was difficult to prevent the scum which formed, especially during the warm months, from passing away

## TABLE 31

SPRINKLING FILTER

Reduction in Biologic Oxygen Demand by Periods
Imhoff Tank (Tank E) and Sprinkling Filter

DAY SEWAGE

| Date | Approx. Yield M.G.D. per A. | Biologic Oxygen Demand Parts per Million | | | Percent Reduction | | |
|---|---|---|---|---|---|---|---|
| | | Grit Chamber | Imhoff Effluent | Filter Effluent | Imhoff Tank | Sprink. Filter | Total |
| April 1, '14—Aug. 1, '14 | 0.987 | 960 | 590 | 60 | 39 | 55 | 94 |
| Aug. 1, '14—Nov. 1, '14 | 1.314 | 980 | 580 | 82 | 41 | 51 | 92 |
| Nov. 1, '14—Nov. 1, '14 | 0.997 | 1000 | 710 | 188 | 29 | 52 | 81 |
| Nov. 1, '15—May 1, '17 | 0.587 | 1090 | 750 | 136 | 31 | 57 | 88 |
| April 1, '14—May 1, '17 | 0.704 | 1030 | 700 | 137 | 32 | 55 | 87 |

## TABLE 32

SPRINKLING FILTER

Reduction of Total Suspended Matter in Secondary Settling Basin
Monthly Averages

| Month | Detention Period Hours | Total Suspended Matter—Parts per Million | | | | | | Percent Reduction | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Influent | | | Effluent | | | | | |
| | | Day | Night | 24-Hour | Day | Night | 24-Hour | Day | Night | 24-Hour |
| 1913 | | | | | | | | | | |
| Dec. 4-18 | 1.0 | 137 | 94 | 125 | 90 | 76 | 84 | 34 | 19 | 32 |
| 1914 | | | | | | | | | | |
| Jan. 3-31 | 1.0 | 109 | 63 | 90 | 63 | 41 | 53 | 42 | 35 | 41 |
| February | 1.0 | 122 | 69 | 104 | 112 | 49 | 90 | 8 | 29 | 14 |
| Mar. 1-9—20-31 | 1.0 | 120 | 120 | 126 | 53 | 121 | 83 | 56 | 1* | 34 |
| Basin Remodelled April 1 | | | | | | | | | | |
| April | 1.0 | 208 | 158 | 183 | 99 | 86 | 85 | 52 | 46 | 54 |
| May† | 1.0 | 126† | 109† | 115† | 72† | 63† | 65† | 43† | 42† | 44† |
| June | 1.0 | 99 | 72 | 86 | 108 | 60 | 92 | 9* | 17 | 7* |
| July 1-22 | 1.0 | 90 | 75 | 84 | 76 | 59 | 70 | 16 | 21 | 17 |
| July 22-31 | 1.5 | 65 | 72 | 67 | 60 | 33 | 50 | 8 | 54 | 25 |
| August | 1.3 | 73 | 64 | 70 | 33 | 32 | 33 | 55 | 50 | 53 |
| September | 1.3 | 113 | 100 | 108 | 78 | 72 | 76 | 31 | 28 | 30 |
| October† | 2.8 | 110 | 81 | 100 | 77 | 39 | 63 | 30 | 52 | 37 |
| Basin remodelled—Nov. 11 to Dec. 23 | | | | | | | | | | |
| 1915 | | | | | | | | | | |
| January | 2.2 | 179 | 154 | 170 | 69 | 72 | 70 | 62 | 55 | 59 |
| February | 2.2 | 197 | 170 | 194 | 80 | 79 | 80 | 59 | 54 | 59 |
| May | 2.2 | 121 | 117 | 119 | 56 | 48 | 53 | 54 | 59 | 56 |
| June | 2.2 | 184 | 164 | 176 | 70 | 58 | 65 | 62 | 65 | 63 |
| July | 1.6 | 124 | 78 | 105 | 51 | 46 | 49 | 59 | 41 | 53 |
| August† | 1.6 | 113 | 91 | 104 | 31 | 23 | 28 | 73 | 75 | 73 |
| September† | 1.6 | 73 | 68 | 71 | 41 | 37 | 39 | 44 | 46 | 45 |
| October† | 1.6 | 72 | 47 | 62 | 38 | 30 | 35 | 47 | 36 | 44 |
| November | 1.6 | 155 | 98 | 131 | 50 | 41 | 46 | 68 | 58 | 65 |

†Part of Month Only.
*Denotes Increase.

# TABLE 33

## SPRINKLING FILTER

### Sludge and Scum Analyses—Secondary Settling Basin

| Date | Sp. Gr. | Percent Moisture | Percent Dry Weight | | | | |
|---|---|---|---|---|---|---|---|
| | | | Nitrogen | Vol. | Fixed | Ether Soluble | |
| | | | | | | Non-acid | Acid |
| | | | **BOTTOM SLUDGE** | | | | |
| 1913 | | | **DORTMUND TANK** | | | | |
| Dec. 10 | 1.00 | 94.5 | 4.54 | 64 | 36 | 4.36 | ....... |
| Dec. 20 | 1.01 | 94.1 | 4.64 | 63 | 37 | 9.56 | ....... |
| 1914 | | | **DORTMUND TANK** | | | | |
| Mar. 27 | 1.02 | 95.5 | 3.76 | 67 | 33 | 4.48 | ....... |
| April 10 | 1.02 | 95.9 | 3.60 | 60 | 40 | 4.66 | ....... |
| April 30 | 1.04 | 90.7 | 3.28 | 54 | 46 | 5.12 | ....... |
| Nov. 2 | 1.02 | 88.8 | 3.60 | 62 | 38 | 6.80 | ....... |
| 1915 | | | **IMHOFF TANK** | | | | |
| Jan. 12 | 1.01 | 98.0 | 4.48 | 66 | 34 | 10.6 | 14.4 |
| Mar. 27 | 1.01 | 96.5 | 4.32 | 66 | 34 | 10.8 | 13.4 |
| | | | **TOP SCUM** | | | | |
| 1913 | | | **DORTMUND TANK** | | | | |
| Dec. 1 | 1.01 | 93.4 | 4.64 | 66 | 34 | 5.7 | ....... |
| Dec. 15 | 1.01 | 93.1 | 4.56 | 69 | 31 | 25.4 | ....... |
| 1914 | | | **DORTMUND TANK** | | | | |
| Oct. 5 | 1.00 | 91.1 | 4.56 | 71 | 29 | 5.9 | ....... |
| Nov. 2 | 1.03 | 89.6 | 3.84 | 70 | 30 | 7.20 | ....... |
| 1915 | | | **IMHOFF TANK** | | | | |
| Mar 27 | 1.00+ | 92.3 | 5.12 | 71 | 29 | 13.6 | 15.6 |
| April 27 | 1.00+ | 93.0 | 4.48 | 67 | 33 | 7.4 | 8.8 |
| June 14 | 0.97 | 89.4 | 4.32 | 70 | 30 | 9.2 | 15.4 |

with the effluent. When the Imhoff tank was substituted in December, 1914, a much better retention was obtained of the solids discharged by the filter. Practically no change in the relative stability of the filter effluent occured during its passage through the settling basin, an average stability of 65 being noted for each of the 19 months during which comparative records are available. Dissolved oxygen was always present.

The sludge retained in the basin was of a dark brown color and of smooth texture, with an odor resembling that of decayed

vegetables. Scum formation, both on the Dortmund tank and on the gas vents of the Imhoff tank, was considerable, particularly during the warm months of the year. At intervals numerous fine white worms appeared in the sludge. Typical analyses of both sludge and scum are given in Table 33. Both sludge and scum showed a much higher nitrogen content than sludges and scums from any other settling device, approaching closely that obtained in the activated sludge. The relative proportions of volatile and fixed matter were about the same as for the Imhoff sludge, while the fat content was very low.

OPERATING RESULTS. After nearly 4½ years of continuous operation, no tendency toward progressive clogging had become manifest. It seems reasonable to conclude that with proper preliminary treatment, this sewage can be treated upon coarse sprinkling filters with no more tendency toward gradual clogging than appears in installations handling domestic sewage, with net rates of application not exceeding ¾ to 1 million gallons per acre daily. It appears possible to secure an effluent with a stability of from 80 to 90 during the summer months and a somewhat reduced, although probably satisfactory, stability during the winter.

In an actual installation, the greatly diminished strength and volume of night flow would allow a considerable degree of rest to the filter daily, probably exceeding in its effect that derived from the complete shutdown, made on Sundays, in the experimental unit which was dosed at a uniform rate throughout the entire 24 hours.

Occasionally local pooling occured, but no permanent or widespread clogging was noted. A heavy bacterial jelly quickly developed after the filter was placed in operation, becoming detached at occasional intervals but being quickly renewed. Nitrification was quickly established after the filter was started, rising high in summer and falling off in winter. Nitrates were always present in the tank effluent. Unloading of the suspended solids proceeded freely and regularly, no permanent retention being indicatd by a comparison of the influent and effluent analyses for suspended matter over the entire life of the filter. Owing to the large amounts of solids discharged by the filter, secondary settling of the effluent appears necessary. These solids can be readily removed. The only troublesome feature is the excessive formation of scum particularly in the Dortmund type of tank. The filter effluent was usually clear

or only slightly turbid. The discharged solids were of granular appearance.

To prevent nozzle clogging, a 12-mesh screen was placed in the orifice box regulating the flow to the filter. This was effective. Occasional cleaning of the nozzles was necessary, however, because of the accumulation of grease or detached fungus growths that developed prolifically in the influent pipe. Some difficulty was experienced in maintaining a satisfactory equality of distribution with the small quantities of liquid handled.

A heavy ring of ice always formed about the nozzle and edges of the filter during the winter, but never of sufficient mass to prevent its operation. The comparatively high temperature of the sewage was probably distinctly beneficial in this respect. Numbers of small white moth flies were common in the vicinity of the filter during the summer months and at certain seasons of the year small white worms and larger red ones appeared in considerable numbers in the effluent.

# CHAPTER VI.

## ACTIVATED SLUDGE—PRELIMINARY TESTS.

Activated sludge experiments were begun on a small scale in 1915. Sewage was drawn from the main orifice box. Air was supplied by a Gardner-Rix Air Compressor, and measured for each tank by individual gas meters.

Tank 1 was a circular galvanized iron tank, 10 ft. high, 2 ft. diameter, with a capacity of approximately 210 gal. The bottom was covered with three layers of screen, 40, 60 and 100 mesh, the latter being on top.

Tank 2 was a circular galvanized iron tank, 9 ft. high, 2 ft. diameter, with a capacity of approximately 190 gal. A filtros plate was cemented in the bottom of this tank on May 28, 1915. Prior to that date the air was supplied through a series of perforated ½-in. galvanized iron pipes. The distribution of air in this tank proved better than in Tank 1.

### TANK 1.

Aeration in Tank 1 began April 30, 1915. The sewage was aerated continuously until May 28, with 0.1 cu. ft. of free air per min. per sq. ft. of surface area. The amount of sludge accumulated during that time was very small. The free ammonia (as N) increased from 22 p. p. m. to 53 p. p. m., the organic nitrogen (as N) decreased from 87 p. p. m. to 53 p. p. m.; the oxygen demand decreased from 886 to 44 p. p. m. The relative stability at the end of this period was 50. The nitrites and nitrates were practically zero. The free ammonia increased, even though purification occurred, probably because of poor distribution of air and settling of solids on the bottom. The total amount of air supplied from April 30 to May 28 was 40.9 cu. ft. per gal. After May 28, the sewage was changed twice a day in order to accumulate a sufficient amount of sludge. On June 14, the volumetric percentage of sludge, after settling one hour, amounted to only 4 percent. From May 28 to June 14, the air supply was kept at 1.3 cu. ft. per gal. of sewage. After June 14, the amount of air was increased to 0.3 cu. ft. per min. per sq. ft. area or 3.4 cu. ft. per gal. On June 25, the sludge

still appeared black. On July 1, the quantity of sludge, after settling one hour, amounted to 29 percent of the volume. The sludge had changed to a dark brown color, appearing more like a typical activated sludge.

Two analyses of sludges (Table 34) were made prior to July 1, one on June 7 and the other on June 17. In both cases the sludge was black in color, containing neither microscopic nor macroscopic living organisms.

**TABLE 34**

ANALYSES OF ACTIVATED SLUDGE, TANK 1.

| Determination | June 7 | June 17 |
|---|---|---|
| Specific Gravity | 1.01 | ........ |
| Percent Moisture | 96.8 | ........ |
| On Dry Basis: Percent. | | |
| Vol. Matter | 69.4 | 82.0 |
| Fixed Matter | 30.6 | 18.0 |
| Organic Nitrogen | 2.9 | 3.4 |
| $P_2O_5$ | 1.3 | 1.6 |
| Fat (without acidification) | 12.3 | 11.6 |
| Fat (with acidification) | 22.8 | 25.1 |

These analyses indicate that the sludge accumulated prior to July 1 was not typical activated sludge. The typical activated sludge of July 1 microscopically showed no worms such as were found at Manchester, Eng., and Urbana, Ill. but did contain various protozoa (infusoria and trachelomonas) and some fungus. The odor was slightly mouldy.

In operating both Tank 1 and Tank 2, the physical appearance and the free ammonia and nitrite determinations served as a ready index of accomplished oxidation, until the cold weather set in. The oxidized sewage was absolutely clear and colorless, without odor. In general the degree of oxidation varied with the amount of colloidal matter left in suspension. In warm weather, the free ammonia in the sewage rapidly diminished on aeration. Nitrification was often completed in summer when the free ammonia was reduced to 10 p. p. m., and certain to be completed when around 1 p. p. m. In cold weather, free ammonia often increased and very low amounts of nitrite and nitrate nitrogen were found in the effluents. During the month of December, perfect stabilities were never reached, although aeration lasted in some cases continuously for 4 days.

In freezing weather the temperature reduction in the tanks 2 ft. diam. was sudden, ranging from 18 to 20 deg. F. in 2½ hr. Records of chilling taken subsequently in one of the wooden

settling tanks (Tank D) did not show such rapid changes. The results obtained in the cold season with the small galvanized iron tanks are not typical of the process, if properly carried out in well protected wooden tanks, or concrete tanks built in the ground.

RESULTS. TANK 1. The results of operation of Tank 1 are given in Table 35. No chemical analyses were made of the effluents. Stability tests showed in general a high degree of stability, but no constant relation between the degree of stability and length of aeration or quantity of air applied. Frequently higher stabilities were obtained in aerating from 1 to 3 hours than in from 6 to 12 hours. The erratic results are probably due to the irregularity of operating conditions and lack of supervision.

**TABLE 35**

RESULTS OF OPERATION, ACTIVATED SLUDGE.

Fill and Draw, Tank 1, July 6 to Dec. 31, 1915.

| Month 1915 | Aeration Period Hours | Percent Sludge 1 Hour Settling | Cu. Ft. Air per Sq. Ft. per Min. | Cu. Ft. Air per Gal. Sewage | Relative Stability | Daily Temp. Deg. Fahr. | |
|---|---|---|---|---|---|---|---|
| | | | | | | Max. | Min. |
| July | 1–3 | 31.0 | .435 | 1.20 | 72.0 | 76 | 64 |
| | 3–6 | 22.5 | .406 | 2.50 | 100.0 | | |
| | 6–9 | 19.6 | .412 | 4.16 | 75.0 | | |
| | 9–12 | 31.5 | .390 | 6.30 | 39.5 | | |
| | Over 12 | 24.5 | .330 | 10.40 | 50.0 | | |
| August | 1–3 | 36.7 | .448 | 1.98 | 71.5 | 72 | 61 |
| | 3–6 | 36.4 | .356 | 2.96 | 80.6 | | |
| | 6–9 | 33.6 | .348 | 3.98 | 89.8 | | |
| | 9–12 | 35.3 | .253 | 4.26 | 71.3 | | |
| September | 1–3 | 33.5 | .295 | 1.10 | 100.0 | 73 | 61 |
| | 3–6 | 30.3 | .369 | 2.84 | 94.1 | | |
| | 6–9 | 34.6 | .357 | 4.64 | 78.2 | | |
| | 9–12 | 32.4 | .257 | 4.80 | 68.6 | | |
| October | 3–6 | 24.5 | .407 | 2.65 | 98.1 | 64 | 49 |
| | 6–9 | 24.7 | .433 | 4.53 | 85.9 | | |
| | 9–12 | 20.7 | .365 | 5.83 | 100.0 | | |
| November | 1–3 | 25.5 | .405 | 1.30 | 71.0 | 51 | 37 |
| | 3–6 | 25.0 | .430 | 3.10 | 83.3 | | |
| | 9–12 | 21.3 | .230 | 3.50 | 87.3 | | |
| | Over 12 | 25.6 | .247 | 6.10 | 68.7 | | |
| December | 6–9 | 20.4 | .336 | 3.66 | 41.0 | 34 | 24 |
| | 9–12 | 24.0 | .360 | 5.30 | 26.0 | | |
| | Over 12 | 16.9 | .270 | 12.75 | 29.0 | | |

RESULTS. TANK 2. Aeration in Tank 2 began April 30, 1915, with a quantity of 0.2 cu. ft. of air per min. per sq. ft. surface area. Instead of attempting to oxidize the first charge of sewage completely, as in Tank 1, the sewage in the tank was changed every few days, after settling the sludge. From April 30 to June 6, the sewage was changed eighteen times, thereby accumulating about 35 percent (volumetric) of sludge, in color grayish black, with an odor slightly mouldy. Various protozoa were noted microsco-

pically but no worms. The amount of air supplied during the period stated, amounted to 5.6 cu. ft. per gal. of sewage. From June 7, systematic oxidation of the sewage began, changing the sludge into a brown, fluffy material within a few days. Two analyses of the sludge (Table 36) were made on June 7 and June 17. The dry sludge had a very decided fertilizer odor.

**TABLE 36**

ANALYSES OF ACTIVATED SLUDGE, TANK 2.

| Determination | June 7 | June 17 |
|---|---|---|
| Specific Gravity | 1.01 | ........ |
| Percent Moisture | 98.3 | ........ |
| On Dry Basis: Percent. | | |
| Vol. Matter | 63.9 | 66.0 |
| Fixed Matter | 36.1 | 34.0 |
| Organic Nitrogen | ........ | 3.4 |
| $P_2O_5$ | ........ | 2.4 |
| Fat (without acidification) | 10.0 | 5.4 |
| Fat (with acidification) | 13.6 | 6.7 |

On June 21, 3 P. M., a sample of the sludge, with a little oxidized sewage, was collected and kept exposed in the laboratory. The protozoa were still alive 48 hours later, showing that aerobic conditions still prevailed, but most of them had died by noon of the next day. The sludge first began to show signs of septicity on the 8th day, the color gradually changing to a grayish black. Later large scale tests showed that activated sludge will become septic in from 6 to 12 hours in warm weather.

**TABLE 37**

RESULTS OF OPERATION, ACTIVATED SLUDGE

Fill and Draw, Tank 2, July 1 to Dec. 31, 1915

| Month 1915 | Aeration Period Hours | Sludge 1 Hour Settling | Air Qu. Ft. per Sq. Ft. per Min. | Air Qu. Ft. per Gal. Sewage | Relative Stability | Deg. Fahr. | |
|---|---|---|---|---|---|---|---|
| | | | | | | Max. | Min. |
| July | 1– 3 | 23.7 | .252 | .77 | 72.5 | 76 | 74 |
| | 3– 6 | 25.1 | .282 | 2.03 | 92.9 | | |
| | 6– 9 | 21.0 | .280 | 3.30 | 72.6 | | |
| | 9–12 | 30.0 | .280 | 4.60 | 77.3 | | |
| | Over 12 | ........ | ........ | ........ | ........ | .... | .... |
| August | 1– 3 | 23.4 | .292 | 1.28 | 90.5 | 72 | 61 |
| | 3– 6 | 29.0 | .240 | 1.99 | 64.7 | | |
| | 6– 9 | 27.4 | .263 | 3.11 | 75.9 | | |
| | 9–12 | 27.5 | .240 | 3.85 | 77.1 | .... | .... |
| September | 1– 3 | 36.3 | .300 | 1.43 | 45.3 | 73 | 61 |
| | 3– 6 | 35.6 | .180 | 1.33 | 28.0 | | |
| | 6– 9 | 35.3 | .262 | 3.80 | 43.0 | | |
| | 9–12 | 36.7 | .254 | 4.91 | 45.8 | | |
| | Over 12 | 37.2 | .175 | 4.90 | 13.0 | | |
| October | 3– 6 | 41.5 | .310 | 2.30 | 100.0 | 64 | 49 |
| | 6– 9 | 35.1 | .298 | 3.55 | 31.3 | | |
| | 9–12 | 29.8 | .287 | 4.79 | 80.5 | | |
| | Over 12 | 57.0 | .280 | 6.80 | 100.0 | | |
| November | 9–12 | 30.6 | .196 | 3.50 | 91.0 | 51 | 37 |
| | Over 12 | 16.2 | .203 | 8.03 | 60.9 | | |
| December | Over 12 | 25.5 | .181 | 6.18 | 34.1 | 34 | 24 |

The results of operation of Tank 2, (Table 37) like Tank 1, were very erratic and inconclusive, due to the irregular method of operation.

Analyses of the activated sludge were made shortly before the operation of the tanks was discontinued (Table 38). Both sludges were brown and fluffy in appearance.

**TABLE 38**

ANALYSES OF ACTIVATED SLUDGE AT FINISH. TANKS 1 AND 2.

| Determination | Tank 1 | Tank 2 |
|---|---|---|
| Specific Gravity | 1.02 | 1.01 |
| Percent Moisture | 98.9 | 98.8 |
| On Dry Basis: Percent. | | |
| Vol. Matter | 85.7 | 77.7 |
| Fixed Matter | 14.3 | 23.3 |
| Organic Nitrogen | 6.4 | 6.6 |
| Fat (without acidification) | 9.3 | 12.9 |
| Fat (with acidification) | 10.3 | 14.7 |

CONCLUSION. On the whole the preliminary experiments demonstrated the feasibility of the new process during the warmer season. Approximately 3 cu. ft. of air were required per gallon of sewage and a period of at least 8 hours in order to obtain a fair stability. A period of ½ hour to 1 hour quiescent sedimentation was sufficient. Observations indicated under-aeration was as harmful as over-aeration. The action of the process seemed to be governed largely by the presence of nitrifying organisms and enzymes, the presence of the more highly developed animal and plant life of minor significance.

# Chapter VII.

## ACTIVATED SLUDGE.

### Operation of Plant.

PERIOD OF OPERATION. Operation of the continuous-flow activated sludge plant was divided into three major periods. In the first period, from Jan. 10, 1916 to March 26, 1917, the sludge was not re-aerated and vertical-flow settling tanks were used up to January 1917, when the horizontal-flow Tank 8 was put in operation. In the second period, from Mar. 27, 1917 to Nov. 14, 1917, re-aeration and re-settling of the sludge was studied, a comparison of 20 and 30 mesh screens was made, and various types of settling tanks were operated, including a specially designed vertical inclined tank. In the third period, from Nov. 16, 1917 to Feb. 12, 1918, only two aeration tanks and one settling tank were used and the sludge was returned directly to the aeration tank without re-aeration or re-settling. This third period was carried out largely as a check on previous work, and to learn the effect of severe winter weather on the simplified process. A fourth period of operation was planned, and the plant entirely remodeled. This period of operation extended from March 8, 1918, to September 30, 1918, but the results obtained were unreliable on account of the lack of skilled field supervision, Mr. Newman having entered the U. S. Army just as the plant was put in operation.

### FIRST PERIOD, JAN. 10, 1916 TO MARCH 26, 1917.

### NO RE-AERATION OF SLUDGE.

Aeration of sewage was started upon the completion of the tanks, as follows:—

| Tank No. | Date, 1916 | Method of Operation |
|---|---|---|
| 3 | Jan. 10 | Fill and Draw |
| 4 | 15 | Fill and Draw |
| 5 | 20 | Fill and Draw |
| 6 | 25 | Fill and Draw |

The tanks were first operated to accumulate sludge. From Feb. 4, to March 8, tanks 3 and 4 were operated on the continuous-

flow plan, with tank 7 as the settling tank. From Mar. 8 to April 18, all tanks were operated on the continuous-flow plan. The results were not satisfactory owing to the poor condition of the air-distribution system. Examination showed septic sludge in the air ducts at the bottom of the tank. The averages for the period April 1 to 15, inclusive, show a use of air at the rate of 0.37 cu. ft. per min. per sq. ft., or 10.6 cu. ft. per gal. of sewage, actual flow, with periods of 25.6 hr. in the aeration tanks and 3.4 hr. in the setting tanks respectively. From April 20 to May 19, the tanks were operated on the fill-and-draw plan, while the air distribution system was being rebuilt.

From May 19 to June 1, the entire plant was operated on a continuous-flow basis but the results were not satisfactory, apparently because the sludge on hand had been over-aerated in the period of sludge storage during repairs. On June 1 the continuous-flow was abandoned, temporarily, the plant being operated from June 1 to July 1 on the fill-and-draw plan in order to accumulate fresh sludge. During this period, also, the perforated air pipes were removed from tanks 5 and 6, and the filtros plates refitted. From July 2, 1916 to Mar. 27, 1917, the plant was operated on the continuous-flow basis, with no re-aeration of the sludge. The period was divided into 15 runs.

AIR MEASUREMENTS. At first the recording device on the 5-inch Venturi air meter did not agree with the simple indicating manometer, directly connected at the meter tube. The manometer readings were therefore recorded hourly. The temperature of the air was taken every two hours at the entrance to the meter. The quantity of air supplied was computed from the manometer readings, reduced to cubic feet of free air at atmospheric pressure and a temperature of 62 deg. Fahr. To reduce the pulsating effect of the blowers, a cylindrical steel tank, 4 ft. diam. by 4 ft. high, was set in the air line between the blowers and the Venturi meter. This brought the readings of the manometer and recorder into substantial agreement.

FILTROS PLATES. Each of the four aeration tanks was fitted with 22 filtros plates (12 by 12 by 1½ in.) which made the net ratio of plate to tank area 1 to 8 (gross 1 to 6). The plates were set in one row down the center of tanks 5 and 6, while in tanks 3 and 4 they were set in rows transverse to the length of the tank. The plates were originally set in wooden boxes lined with

galvanized iron, with bearing surface only along their length. The spaces between the plates were filled with "Jointite". Wooden strips were placed over their edges longitudinally along the boxes, in order to hold them down. Each box, containing 3 or 4 plates, was supplied with air by means of a 1½ inch pipe leading from a main air header over each tank. With this arrangement, the air supply to each box could be regulated, which was essential, as the plates first supplied varied in porosity. Plates of the same porosity were placed in the same box.

During the period April 20 to May 19, 1916, the tanks were operated on the fill-and-draw plan, while the filtros plates were examined. Examination showed cracked plates in all tanks. In tanks 5 and 6, particularly, every plate was broken longitudinally at the centre, in a single row down the middle of the tank. This apparently due to insufficient bearing surface transversely across the trough. The filtros plates were in better condition in tanks 3 and 4, though many were cracked. All the tanks were then equipped with new boxes with galvanized iron, in which each plate was supported on all four sides. The plates were first bedded in Portland cement mortar. The joint spaces were filled with "Jointite". Band-iron strips were then fastened over the edges.

SAMPLING DATA. Samples were taken every hour for chemical analyses. On working days these were made up into composites for the day flow from 7 A. M. to 9 P. M. and for the night flow from 9 P. M. to 7 A. M. On Sundays and holidays, a composite sample was made up for the 24 hours.

Composite samples were made from the day screened sewage, the night sewage, and the effluent of the settling tank, both for day and night flows. Hourly samples were taken of the settling tank effluent to determine the stability by the methylene blue method. Beginning with August 27, 1916, samples for relative stability were taken from the outlets of aeration tanks 4 and 5. Beginning with Oct. 30, 1916, samples were taken every two hours of the effluent of the settling tank for the biological oxygen consumption test by the saltpeter method. These samples were combined into day and night composites. Beginning with Nov. 24, 1916, samples were taken every six hours of the effluent of the settling tank for the dissolved oxygen content.

Samples of the screenings were taken daily for moisture determinations. Weekly composites were made up for complete

analyses. Samples of the activated sludge were taken weekly from the outlet end of the final aeration tank (tank 6) for complete analyses. All sludge removed was sampled for the moisture content.

Settling tests of the sludge in all tanks were made every four hours. These tests were carried out in 100 c. c. graduated cylinders, the readings being recorded when one-half hour and one hour had elapsed.

DETENTION PERIODS. Detention periods in the aeration tanks have been calculated from the total volume of sewage treated, plus sludge returned, into the total volume of aeration tanks.

Settling periods have been calculated from the volume of effluent into the volume of settling space (from bottom of influent pipe to flow line). As sludge is removed continuously from all settling tanks, the volume of sludge entering with aerated sewage need not be considered as remaining in the tank for more than a few minutes. Flow tests have shown that the actual detention period is longer than that calculated from the volume of sewage plus sludge into the tank volume. These tests showed the error of using the latter method of computation.

OPERATING CONDITIONS. From July 1, 1916 to March 26, 1917, inclusive, 15 separate runs were made, varying the rate of flow of sewage and the settling period. During the entire period, the day sewage was passed through a 30-mesh rotary screen, except on Sundays and holidays and during Run 7 (Sept. 17 to Oct. 15, 1916).

The Report on Industrial Waste from the Stockyards and Packingtown (1914) showed that on working days the day sewage was much stronger than the night. The operation of the plant, however, was not varied during the 24 hours, except to bypass the screen from 9 P. M. to 7 A. M., and to shut off the sewage whenever the excess accumulation of sludge had to be wasted, normally about once a day. This interruption in the operation would be avoided in a large plant, as the surplus sludge on hand would be sufficient to permit continuous removal. On Sundays and holidays, the sewage approximated the night flow. The screen was then by-passed, and the amount of air applied was frequently reduced.

## TABLE 39

OPERATING DATA ON STRAIGHT FLOW ACTIVATED SLUDGE TESTS.

July 2, 1916 to March 26, 1917.

Operation Results—(Day, Nights, Sunday and Holiday Average)

| No. of Run | Period of Operation | No of Days | Temperature Deg. F. | | | Sewage Treated Gallons per 24 Hours | | Ratio of Flows Sludge to Sewage | Period in Hours | | Free Air Used Cu. Ft. per | | Per Ct. Sludge Aeration Tanks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Atmos. | Comp. Air | Effluent | Rate | Actual | | Aeration | ettling | Sq. Ft. per Minute | Gallon Sewage | |
| | 1916 | | | | | | | | | | | | |
| 1 | July 2 to 10 | 9 | 71 | 99 | .... | 57,500 | 50,900 | 0.76 | 10.2 | 2.4 | 0.25 | 3.91 | 29 |
| 2 | July 11 to 14 | 4 | 78 | 110 | .... | 52,000 | 50,500 | 0.50 | 13.2 | 2.7 | 0.28 | 4.41 | 19 |
| 3 | July 15 to 26 | 12 | 80 | 111 | .... | 53,500 | 52,960 | 0.48 | 13.0 | 2.6 | 0.28 | 4.22 | 32 |
| 4 | July 27 to Aug. 14 | 19 | 81 | 104 | .... | 53,600 | 53,300 | 0.48 | 12.3 | 1.6 | 0.26 | 3.95 | 32 |
| 5 | Aug. 15 to 28 | 14 | 76 | 108 | .... | 79,500 | 76,800 | 0.48 | 9.0 | 1.5 | 0.34 | 3.50 | 24 |
| 6 | Aug. 29 to Sept. 16 | 19 | 70 | 100 | .... | 72,750 | 67,600 | 0.70 | 8.8 | 1.7 | 0.31 | 3.72 | 46 |
| 7 | Sept. 17 to Oct. 14 | 28 | 60 | 94 | .... | 72,750 | 67,500 | 0.69 | 9.3 | 1.8 | 0.31 | 3.66 | 48 |
| 8 | Oct. 15 to 22 | 8 | 49 | 82 | 69 | 72,750 | 68,700 | 0.65 | 8.9 | 1.6 | 0.28 | 3.27 | 32 |
| 9 | Oct. 23 to Nov. 23 | 32 | 46 | 95 | 70 | 97,000 | 85,000 | 0.67 | 7.2 | 1.1 | 0.44 | 4.17 | 30 |
| 10 | Nov. 24 to Dec. 7 | 14 | 44 | 92 | 69 | 80,250 | 67,300 | 0.49 | 9.4 | 1.3 | 0.48 | 5.63 | 58 |
| 11 | Dec. 8 to 15 | 8 | 23 | 84 | 60 | 80,250 | 70,840 | 0.54 | 9.3 | 1.3 | 0.59 | 6.52 | 25 |
| | 1917 | | | | | | | | | | | | |
| 12 | Dec. 16 to Jan. 7 | 23 | .... | 70 | 58 | 80,250 | 72,600 | 0.66 | 8.5 | 1.3 | 0.38 | 4.07 | 25 |
| 13 | Jan. 8 to Feb. 4 | 28 | .... | 60 | 55 | 55,000 | 47,700 | 0.93 | 10.9 | 2.0 | 0.24 | 3.97 | 19 |
| 14 | Feb. 5 to Mar. 5 | 29 | .... | 73 | 56 | 81,600 | 70,700 | 0.79 | 8.1 | 1.3 | 0.28 | 3.17 | 28 |
| 15 | Mar. 6 to Mar. 26 | 18 | .... | 77 | 56 | 48,500 | 42,200 | 0.67 | 6.9 | 2.2 | 0.45 | 4.23 | 20 |

# TABLE 40

SUMMARY OF ANALYTICAL DATA ON STRAIGHT FLOW ACTIVATED SLUDGE TESTS
July 2, 1916 to March 26, 1917

| No. of Run | Period of Operation 1916 | Sample | Influent P. P. M. T.S.M. | Influent Nitrogen as Organic N | Influent Nitrogen as Free Amm. | Effluent Parts per Million T.S.M. | Effluent Nitrogen as Organic N | Effluent Nitrogen as Free Amm. | Effluent Nitrogen as Nitrites | Effluent Nitrogen as Nitrates | Turbidity | Dissolved Oxygen | B.O.C. | Average Relative Stability Effluent | Tank 5 | Tank 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | July 2 to 10 | Day | 365 | 42 | 22 | 87 | 9.7 | 8.2 | 2.5 | 4.7 | 23 | | | 70 | | |
| | | Night | 152 | 34 | 15 | 52 | 5.5 | 4.2 | 2.65 | 7.1 | 14 | | | 100 | | |
| | | Sunday | 156 | 19 | 13 | 52 | 7.1 | 3.8 | 0.8 | 8.6 | 17 | | | 96 | | |
| | | Average | 203 | 32 | 17 | 65 | 7.7 | 5.6 | 2.0 | 6.7 | 18 | | | 87 | | |
| 2 | July 11 to 14 | Day | 449 | 50 | 23 | 113 | 9.1 | 11.8 | 3.37 | 3.69 | 28 | | | 52 | | |
| | | Night | 175 | 27 | 16 | 71 | 13.0 | 5.8 | 5.6 | 5.9 | 26 | | | 87 | | |
| | | Sunday | | | | | | | | | | | | | | |
| | | Average | 335 | 40 | 20 | 96 | 10.7 | 9.3 | 4.3 | 4.61 | 27 | | | 67 | | |
| 3 | July 15 to 26 | Day | 302 | 43 | 19 | 71 | 7.8 | 4.1 | 5.3 | 2.8 | 18 | | | 80 | | |
| | | Night | 136 | 18 | 12 | 73 | 7.2 | 2.1 | 5.2 | 4.6 | 17 | | | 93 | | |
| | | Sunday | 157 | 25 | 11 | 87 | 12.1 | 1.5 | 5.9 | 4.9 | 17 | | | 97 | | |
| | | Average | 220 | 32 | 15 | 75 | 8.1 | 2.9 | 5.6 | 3.8 | 18 | | | 90 | | |
| 4 | July 27 to Aug. 14 | Day | 370 | 48 | 17 | 55 | 7.8 | 7.2 | 6.3 | 2.1 | 14 | | | 90 | | |
| | | Night | 168 | 21 | 12 | 90 | 6.8 | 5.2 | 6.5 | 3.4 | 13 | | | 95 | | |
| | | Sunday | 131 | 28 | 10 | 31 | 5.4 | 1.7 | 7.0 | 5.1 | 12 | | | 100 | | |
| | | Average | 262 | 36 | 14 | 64 | 6.9 | 5.7 | 6.5 | 2.9 | 14 | | | 93 | | |
| 5 | Aug. 15 to 28 | Day | 360 | 45 | 20 | 52 | 7.1 | 13.7 | 1.74 | 6.15 | 18 | | | 28 | | |
| | | Night | 147 | 23 | 12 | 64 | 8.2 | 10.3 | 3.12 | 4.55 | 13 | | | 69 | | |
| | | Sunday | 176 | 31 | 10 | 50 | 6.5 | 9.5 | 3.6 | 3.3 | 20 | | | 95 | | |
| | | Average | 257 | 35 | 16 | 56 | 7.4 | 11.9 | 2.50 | 5.17 | 17 | | | 52 | | |
| 6 | Aug. 29 to Sept. 16 | Day | 380 | 53 | 17 | 18 | 4.8 | 7.0 | 1.75 | 1.86 | 13 | | | 72 | 68 | 30 |
| | | Night | 256 | 28 | 12 | 21 | 5.7 | 4.2 | 1.77 | 4.06 | 11 | | | 73 | 90 | 52 |
| | | Sunday | 155 | 33 | 10 | 14 | 4.4 | 2.1 | 3.6 | 9.5 | 12 | | | 89 | 94 | 87 |
| | | Average | 301 | 41 | 14 | 18 | 5.1 | 5.2 | 2.05 | 3.84 | 12 | | | 75 | 81 | 51 |

Note T.S.M. means Total Suspended Matter

## TABLE 40—Continued

SUMMARY OF ANALYTICAL DATA ON STRAIGHT FLOW ACTIVATED SLUDGE TESTS

July 2, 1916 to March 26, 1917

| No. of Run | Period of Operation 1916 | Sample | Influent P. P. M. T.S.M. | Influent Nitrogen as Organic N | Influent Nitrogen as Free Amm. | Effluent Parts per Million T.S.M. | Effluent Nitrogen as Organic N | Effluent Nitrogen as Free Amm. | Effluent Nitrogen as Nitrites | Effluent Nitrogen as Nitrates | Turbidity | Dissolved Oxygen | B.O.C. | Average Relative Stability Effluent | Tank 5 | Tank 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 1916 Sept. 17 to Oct. 14 | Day | 552 | 61 | 23 | 32 | 6.9 | 12.0 | 1.10 | 1.55 | 17 | ........ | ........ | 59 | 44 | 23 |
| | | Night | 318 | 32 | 13 | 65 | 9.3 | 11.4 | 1.51 | 1.70 | 14 | ........ | ........ | 65 | 75 | 42 |
| | | Sunday | 172 | 21 | 11 | 47 | 11.8 | 8.0 | 1.24 | 3.45 | 12 | ........ | ........ | 92 | 81 | 39 |
| | | Average | 410 | 45 | 18 | 46 | 8.4 | 11.2 | 1.26 | 1.89 | 15 | ........ | ........ | 66 | 58 | 31 |
| 8 | Oct. 15 to 22 | Day | 490 | 59 | 18 | 46 | 9.2 | 18.5 | 0.23 | 0.26 | 20 | 0.6 | .... | 36 | 37 | 10 |
| | | Night | 268 | 34 | 13 | 42 | 8.7 | 13.9 | 0.57 | 1.34 | 14 | 1.0 | .... | 41 | 34 | 15 |
| | | Sunday | 211 | 25 | 9 | 24 | 7.6 | 10.8 | 1.16 | 5.13 | 10 | 1.7 | .... | 83 | 44 | 23 |
| | | Average | 340 | 42 | 14 | 38 | 8.6 | 14.8 | 0.61 | 2.07 | 16 | 1.1 | .... | 52 | 37 | 14 |
| 9 | Oct. 23 to Nov. 23 | Day | 532 | 77 | 19 | 31 | 10.9 | 29.2 | 0.10 | 0.27 | 22 | 0.8 | 62 | 20 | 17 | .... |
| | | Night | 325 | 42 | 13 | 36 | 10.8 | 27.9 | 0.10 | 0.40 | 25 | 0.7 | 57 | 23 | 16 | .... |
| | | Sunday | 389 | 38 | 14 | 22 | 8.1 | 27.0 | 0.27 | 0.57 | 16 | 1.1 | 25 | 38 | 30 | .... |
| | | Average | 437 | 59 | 17 | 32 | 10.5 | 28.5 | 0.12 | 0.35 | 22 | 0.8 | 56 | 23 | 19 | .... |
| 10 | Nov. 24 to Dec. 7 | Day | 593 | 84 | 20 | 39 | 1.7 | 31.0 | 0.05 | 0.18 | 51 | 0.3 | 65 | 5 | 4 | 4 |
| | | Night | 321 | 62 | 16 | 43 | 1.0 | 29.0 | 0.07 | 0.09 | 45 | 0.6 | 47 | 9 | 4 | 4 |
| | | Sunday | 299 | 37 | 15 | 25 | 1.4 | 26.0 | 0.11 | 0.13 | 40 | 2.2 | 49 | 22 | 8 | 5 |
| | | Average | 441 | 67 | 17 | 38 | 1.4 | 29.0 | 0.08 | 0.14 | 47 | 0.8 | 56 | 10 | 5 | 4 |
| 11 | Dec. 8 to 15 | Day | 477 | 75 | 17 | 63 | 1.4 | 34.0 | 0.03 | 0.23 | 43 | 0.9 | 68 | 21 | 22 | 12 |
| | | Night | 391 | 61 | 14 | 52 | 1.1 | 29.0 | 0.08 | 0.13 | 34 | 0.9 | 65 | 33 | 33 | 25 |
| | | Sunday | 274 | 12 | 10 | 34 | 1.0 | 27.0 | 0.16 | 0.08 | 20 | 0.1 | 35 | 30 | 52 | 34 |
| | | Average | 420 | 62 | 15 | 55 | 1.3 | 31.0 | 0.06 | 0.18 | 37 | 0.8 | 63 | 27 | 30 | 19 |
| 12 | Dec. 16 to Jan. 7, '17 | Day | 538 | 98 | 19 | 75 | 2.4 | 27.0 | 0.00 | 0.22 | 68 | 0.1 | 112 | 6 | 6 | .... |
| | | Night | 255 | 40 | 12 | 69 | 1.8 | 27.0 | 0.01 | 0.13 | 59 | 0.8 | 86 | 11 | 8 | .... |
| | | Sunday | 247 | 32 | 11 | 40 | 1.3 | 18.0 | 0.06 | 0.19 | 32 | 1.7 | 58 | 26 | 28 | .... |
| | | Average | 375 | 63 | 15 | 64 | 2.0 | 25.0 | 0.02 | 0.18 | 56 | 0.7 | 90 | 13 | 12 | .... |

## TABLE 40—Continued

SUMMARY OF ANALYTICAL DATA ON STRAIGHT FLOW ACTIVATED SLUDGE TESTS

July 2, 1916 to March 26, 1917

| No. of Run | Period of Operation 1916 | Sample | Influent P. P. M. T.S.M. | Influent Nitrogen as Organic N | Influent Nitrogen as Free Amm. | Effluent T.S.M. | Effluent Parts per Million Nitrogen as Organic N | Free Amm. | Nitrites | Nitrates | Turbidity | Dissolved Oxygen | B.O.C. | Average Relative Stability Efflu-ent | Tank 5 | Tank 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 1917 Jan. 8 to Feb. 4 | Day | 465 | 76 | 16 | 46 | 1.3 | 25.0 | 0.01 | 0.08 | 26 | 1.4 | 42 | 36 | 25 | .... |
| | | Night | 202 | 36 | 11 | 71 | 1.3 | 24.0 | 0.01 | 0.09 | 30 | 2.0 | 45 | 37 | 29 | .... |
| | | Sunday | 154 | 19 | 11 | 54 | 1.2 | 19.0 | 0.03 | 0.04 | 20 | 2.6 | 33 | 51 | 51 | .... |
| | | Average | 326 | 53 | 13 | 56 | 1.3 | 24.0 | 0.01 | 0.07 | 27 | 1.8 | 42 | 38 | 30 | .... |
| 14 | Feb. 5 to Mar. 5 | Day | 480 | 72 | 15 | 32 | 1.3 | 23.0 | 0.01 | 0.13 | 41 | 1.1 | 45 | 21 | 15 | .... |
| | | Night | 207 | 31 | 8 | 33 | 1.3 | 20.0 | 0.02 | 0.06 | 40 | 1.3 | 41 | 20 | 18 | .... |
| | | Sunday | 104 | 17 | 6 | 20 | .8 | 17.0 | 0.05 | 0.07 | 19 | 3.3 | 33 | 38 | 27 | .... |
| | | Average | 330 | 50 | 11 | 30 | 1.2 | 21.0 | 0.02 | 0.10 | 38 | 1.5 | 40 | 23 | 18 | .... |
| 15 | Mar. 6 to 26 | Day | 427 | 56 | 15 | 23 | 1.2 | 18.0 | 0.03 | 0.18 | 46 | 1.2 | 40 | 24 | .... | .... |
| | | Night | 173 | 25 | 10 | 22 | .9 | 15.0 | 0.04 | 0.26 | 32 | 1.7 | 38 | 30 | .... | .... |
| | | Sunday | 165 | 24 | 10 | 15 | 1.4 | 15.0 | 0.09 | 0.22 | 20 | 2.6 | 33 | 51 | .... | .... |
| | | Average | 295 | 40 | 13 | 22 | 1.2 | 17.0 | 0.04 | 0.21 | 37 | 1.6 | 38 | 31 | .... | .... |

The sludge was returned continuously from the settling tank to the inlet of tank 3, by either a 1½-inch or 2-inch centrifugal pump, or a 2½-inch air lift. The amount returned varied with the rate of flow of the sewage and the settling qualities of the sludge.

During operation various flows were tried to obtain different aeration and settling periods. The rate of flow of sewage was kept constant throughout each run. The air was varied to obtain a clear and fairly stable effluent. During cold weather, the plant was operated for the greater part of the time to determine the minimum air consumption, for different aeration periods necessary to produce a clarified effluent, disregarding the relative stability.

All the air was passed through a 40-mesh brass screen before going to the blowers. The application of air was generally at a much lower rate on Sundays and holidays, except when the sludge settled very slowly. Excess aeration was then resorted to. During the winter the air was generally applied at the same rate on Sunday as on week days, so as to condition the sludge properly, and prepare it for the heavy Monday load.

## AERATION PERIODS AND ANALYTICAL RESULTS.

The operating data for the fifteen runs into which the first period was divided are given in Table 39, the analytical results in Tables 40 and 41. Results broadly are grouped under summer conditions from Run 1 through Run 8, (July 2 to Oct. 22, 1916), and under winter conditions from Run 9 through Run 15 (Oct. 23, 1916 to March 26, 1917).

The strength of the crude sewage varied from month to month, increasing during the fall and reaching a maximum in Run 10 (Nov. 24 to Dec. 10, 1916). This was due to the greater kill in the packinghouses and should be considered when comparing results.

The aeration periods during the first four runs and the settling periods during the first three runs were longer than found necessary in later tests. More air was supplied than necessary, with the long aeration period. The analytical results for the first four runs were excellent, and better than those for the next four runs, which, however, were satisfactory. In Runs 5 to 8, the aeration and settling periods were almost constant and the amount and rate of air consumption varied only slighty. An excessive amount of sludge was returned to the aeration tanks during Runs 6, 7 and 8 due to its light, flocculent nature and to the increased flow of sewage.

The absence of the screen during Run 7 resulted in an accumulation of material similar to screenings on the tie rods at the tops of tanks 3 and 4 and similar material also in the sludge orifice-box. The sludge pumps were examined at the end of the run. Considerable hair and fibrous material was found around the shaft between the casing and impellor, and also around the discharge pipe.

The screen was again operated during Run 8. The air consumption during this run was reduced to the minimum consistent with the production of a good effluent.

The analytical results were satisfactory throughout all of the first period. The reduction of ammonia nitrogen was fairly high during July, but decreased gradually from 67 per cent in Run 1 to 38 per cent in Run 7. The nitrite plus nitrate content averaged about 7.0 p. p. m., with the nitrite content almost as great as the nitrate. The relative stabilities were satisfactory in general. Samples which did not decolorize in ten days were rated 100 per cent stable.

Starting with Run 6, samples were taken from the effluent ends of tanks 4 and 5 in sampling cans, settled one hour, and the supernatant liquid tested for stability with methylene blue. The samples from tank 4 were usually rather unstable, but those from tank 5 were nearly as stable as the final effluent, indicating that aeration in the last tank served largely to condition the sludge rather than to produce a satisfactory effluent.

The rate of nitrification decreased decidedly during Run 8, indicating inhibition of the normal activity of the nitrifying bacteria in cold weather. The production of nitrites and nitrates was still less in the succeeding periods, showing the necessity of considering summer and winter results from different standpoints.

Operating conditions were varied several times under winter conditions. Starting with Run 9 (Oct. 23 to Nov. 24, 1916), the aeration and settling periods were cut down to the minimum, 7.2 and 7.1 hours respectively, but the air was maintained at a very high rate, 0.44 cu. ft. per sq. ft. per minute or 4.17 cu. ft. per gal. The results were not satisfactory, however, the nitrates decreasing to a few tenths of a part per million. A new settling tank, tank D (Fig 14), was used during this and following runs. The hopper of this tank had much steeper slopes than the hopper of Tank 7, thereby reducing the trouble due to sludge clinging to the sides of the hopper.

During the next run (Run 10, Nov. 24 to Dec. 8, 1916), the aeration period was increased to 9.4 hours and in addition the air was increased to 5.63 cu. ft. per gal. in an attempt to promote nitrification. Nitrification showed no increase, however. The ammonia nitrogen increased greatly. In Run 11 (Dec. 8 to 16, 1916) a stable effluent was sought by increasing the air supply, keeping the rate of flow of sewage, aeration and settling periods the same as during the previous run. Even the excessive amount of 6.52 cu. ft. of air per gal. of sewage was not sufficient to improve the quality of the effluent.

In the next run (Run 12, Dec. 16, 1916 to Jan. 7, 1917), the air was cut down to 4.07 cu. ft. per gal. Practically as good an effluent was obtained as with 6.5 cu. ft., even though a somewhat shorter aeration period obtained. The horizontal-flow settling tank (tank 8) was operated during part of this run until the rate of flow of sewage exceeded its capacity.

In the following run (Run 13, Jan. 8 to Feb. 4, 1917) the aeration period was increased to 10.9 hours, the air kept at 3.97 cu. ft. per gal., to determine whether a longer aeration period would improve nitrification. A sightly better effluent was obtained but the nitrates were still very low, less than 0.1 p. p. m.

In Run 14 (Feb. 5 to March 5, 1917), the aeration period was shortened to 8.1 hours and the air reduced to 3.17 cu. ft. per gal. In Run 15 (Feb. 5 to March 5, 1917), while the tanks were being overhauled and necessary changes made for re-aeration of sludge, only tanks 3 and 4 were operated, directly connected to the settling tanks. A short period of aeration was obtained, 6.9 hours, but a larger amount of air was supplied, 4.23 cu. ft. per gal. In both these runs no improvement in the effluent was noticed.

Dissolved oxygen and biochemical oxygen demand increased generally with a decrease in atmospheric temperature. The oxygen demand varied with the total suspended matter and organic nitrogen.

All stabilities during the winter runs were below 40, but as operating standards during cold weather may not require a stable effluent, it was felt that clarification was sufficient. The reduction in suspended solids would have been greater if all the sludge could have been retained in the settling tank. Quite frequently particles of sludge would escape with the effluent. This should not properly be chargeable to the process, but to the design and operation of the settling tank.

# TABLE 41

ANALYTICAL DATA ON STRAIGHT FLOW ACTIVATED SLUDGE TESTS, SHOWING REDUCTION IN VARIOUS CONSTITUENTS.

July 2, 1916 to March 26, 1917.

| No. of Run | Total Suspended Matter | | | Nitrogen as | | | | | | | | Diss. Ox. | B.O.C. | Turbidity | Average Relative Stability | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Organic | | | Free Ammonia | | | Nitrites | Nitrates | | | | | | |
| | Influent | Effluent | Percent Reduction | Influent | Effluent | Percent Reduction | Influent | Effluent | Percent Reduction | | | | | | Effluent | Tank 5 | Tank 4 |
| 1 | 203 | 65 | 68.0 | 32 | 7.7 | 76.0 | 17 | 5.6 | 67.0 | 2.0 | 6.7 | ------ | ---- | 18 | 87 | ---- | ---- |
| 2 | 335 | 96 | 71.3 | 40 | 10.7 | 73.2 | 20 | 9.3 | 53.5 | 4.3 | 4.61 | ------ | ---- | 27 | 67 | ---- | ---- |
| 3 | 220 | 75 | 66.0 | 32 | 8.1 | 74.7 | 15 | 2.9 | 80.8 | 5.6 | 3.8 | ------ | ---- | 18 | 90 | ---- | ---- |
| 4 | 262 | 64 | 76.0 | 36 | 6.9 | 81.0 | 14 | 5.7 | 59.3 | 6.5 | 2.9 | ------ | ---- | 14 | 93 | ---- | ---- |
| 5 | 257 | 56 | 78.0 | 35 | 7.4 | 78.9 | 16 | 11.9 | 25.6 | 2.5 | 5.17 | ------ | ---- | 17 | 52 | ---- | ---- |
| 6 | 301 | 18 | 94.0 | 41 | 5.1 | 87.6 | 14 | 5.2 | 63.0 | 2.05 | 3.84 | ------ | ---- | 12 | 75 | 81 | 51 |
| 7 | 410 | 46 | 88.8 | 45 | 8.4 | 81.4 | 18 | 11.2 | 37.8 | 1.26 | 1.89 | ------ | ---- | 15 | 66 | 58 | 31 |
| 8 | 340 | 38 | 88.8 | 42 | 8.6 | 79.5 | 14 | 14.8 | −5.7 | 0.61 | 2.07 | 1.1 | ---- | 16 | 52 | 37 | 14 |
| 9 | 437 | 32 | 92.9 | 59 | 10.5 | 82.2 | 17 | 28.5 | −67.7 | 0.12 | 0.35 | 0.8 | 56 | 22 | 23 | 19 | ---- |
| 10 | 441 | 38 | 91.7 | 67 | 14.0 | 79.2 | 17 | 29.0 | −70.7 | 0.08 | 0.14 | 0.8 | 56 | 47 | 10 | 5 | 4 |
| 11 | 420 | 55 | 87.0 | 62 | 13.0 | 79.1 | 15 | 31.0 | −106.5 | 0.06 | 0.18 | 0.8 | 63 | 37 | 27 | 30 | 19 |
| 12 | 375 | 64 | 83.0 | 63 | 20.0 | 68.3 | 15 | 25.0 | −66.7 | 0.02 | 0.18 | 0.7 | 90 | 56 | 13 | 12 | ---- |
| 13 | 326 | 56 | 83.0 | 53 | 13.0 | 75.5 | 13 | 24.0 | −78.5 | 0.01 | 0.07 | 1.8 | 42 | 27 | 38 | 30 | ---- |
| 14 | 330 | 30 | 91.0 | 50 | 12.0 | 76.0 | 11 | 21.0 | −91.0 | 0.02 | 0.10 | 1.5 | 40 | 38 | 23 | 18 | ---- |
| 15 | 295 | 22 | 92.5 | 40 | 12.0 | 70.0 | 13 | 17.0 | −30.8 | 0.04 | 0.21 | 1.6 | 38 | 37 | 31 | | ---- |

## SETTLING TANKS.

TANK 7. The hopper of the settling tank (tank 7) was originally built with side slopes of 30 degrees with the horizontal. This proved too flat. Throughout its use, considerable difficulty was experienced in the septicization of the sludge in the settling tank, due partly to adherence to the hopper slopes, and also to the undersurface of the outlet trough. Careful cleaning by pushing a galvanized iron scraper up and down proved fairly satisfactory, if executed several times a day. The result of such scraping was clearly noticed in the black color of the sludge returned to the plant directly after the scraping.

On July 27, the settling capacity of the settling tank was reduced from 5840 to 3570 gal. by shortening the inlet pipe. The settling capacity of tank 7 was increased, on Aug. 17 from 3570 to 5070 gal. by lengthening the inlet pipe.

During the period Aug. 29 to Sept. 16, the sludge settled slowly and adhered less persistently to the bottom of the tank, flowing more readily with the high moisture content of 99 per cent and over.

Considerable trouble was experienced during Run 7 with sludge, not completely activated, as noted by its slow settling properties. Sludge in this condition has a high moisture content and flows more readily. The tank was cleaned on Sept. 26.

TANK D. On Oct. 19, 1916, settling tank D was substituted for tank 7. This tank gave excellent results at all times, no trouble being experienced in the septicization of the sludge. The slope of 45 degrees on the bottom of the effluent trough, and the slope of 1.8 vertical to 1 horizontal of the hopper bottom, proved sufficient to prevent sludge from adhering to either. In this tank the sewage had a vertical flow of 6 ft. 9 in. and a horizontal flow of 4 ft. to the effluent trough which was notched with V-shaped openings.

The theoretical settling period given in the tables was calculated from the flow of sewage entering the plant into the volume of the settling compartment (volume between inlet and outlet). The volume of sludge removed continuously from the settling tank was not taken into consideration. The theoretical detention period in this tank varied from 1.1 to 1.8 hours, with equivalent vertical velocities of 6.1 to 3.7 ft. per hr.

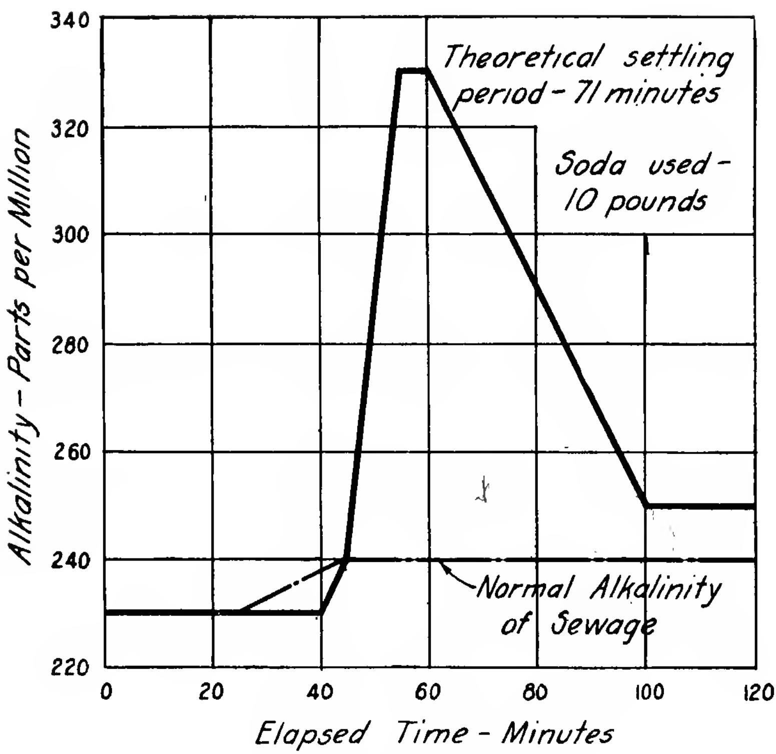


**Fig. 17. Flow Test on Settling Tank D.**

On Feb. 15 and 26, 1916, flow tests were made on tank D to determine the actual detention or settling period. Ten pounds of soda ash were used in each test. Samples of the inlet and outlet were taken at regular intervals and tested for alkalinity. The results obtained on Feb. 26 (Fig. 17) show an actual settling period of about 1 hour, while the theoretical period was 71 minutes.

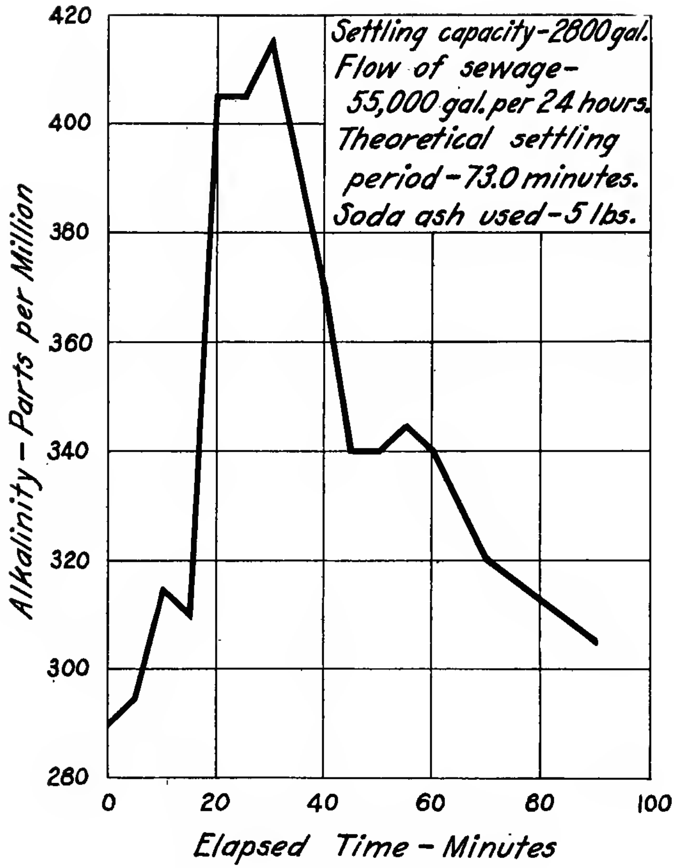


**Fig. 18. Flow Test on Settling Tank 8.**

TANK 8. During the early part of January, 1917, the horizontal flow settling tank (tank 8) was put in use. To secure proper distribution at the inlet end of tank, a baffle was built across the tank, 8 in. from the inlet end and 4 ft. 8 in. deep. The sewage enters 4 ft. 6 in. below the surface, through a distributor containing 7 holes, each 2½ in. diam.

In several tests made during January, satisfactory results were obtained only when the sludge exhibited fast settling properties. The rate of flow of sewage was too high for the size of the tank. With a decreased flow of sewage from March 6 to 26, very good results were obtained with tank 8 with a theoretical settling period of 2.2 hours.

On January 10, 1917, a flow test (Fig. 18) was made on tank 8,

similar to the tests made on tank D, using, however, only 5 lb. of soda ash. This indicated an actual settling period of about 35 minutes, while the theoretical period was 73 minutes. The theoretical horizontal velocity was 12 ft. per hr., whereas the actual horizontal velocity was 26 ft. per hr.

GENERAL. Only tentative conclusions can be reached on the horizontal flow type of tank based on experiments with a horizontal distance of travel of only 15 feet. With the tanks tested the per cent of effective settling volume was much lower with the horizontal flow than the vertical-flow tank. In the horizontal-flow type of tank, the sludge compartment consisted of several hoppers, necessitating removing sludge from each hopper continuously thus increasing the supervision required for proper operation.

As the sludge accumulated at a rate too slow to waste continuously, the surplus was allowed to remain in the settling tanks and removed once or twice per day, depending upon conditions. The sewage flow was shut off while removing sludge, but aeration was not interrupted. When sewage was again admitted to the aeration tanks after such shut-downs, the effluent contained a small amount of flocculent material in suspension. As the sludge settled in the tank, forming an even layer or blanket, the effluent became clear, the fine flocculent and colloidal matter filtering out while passing through this layer of sludge. If the sludge line rose too high and was less than one foot below the outlet trough, fine particles of sludge passed off with the effluent. The clearest effluent was obtained when the sewage passed through a sludge blanket about 3 feet thick. A sludge layer can readily be maintained in a large plant, where sufficient sludge is accumulated to permit the continuous removal of the excess, and where the tank is deep enough to allow reasonable fluctuations in sewage flow.

SLUDGE CIRCULATION. The circulation of sludge was controlled by a valve on the discharge line from the pumps before entrance to the orifice box. Even with the small centrifugal pump used, only occasional cleaning was necessary to remove fibrous material around the shaft and runner. Most of the heavy coarse matter in the raw sewage was caught by the rotary screen. The best working results were secured with the entrance to the sludge piping in the tank looking up. The air lift used in pumping sludge proved more reliable on a small scale than a pump.

SLUDGE RATIO. The average per cent of sludge by volume

in the aerating tanks as given in Table 39, was determined by settling a sample from tank 6, the last tank, one hour in a 100 cc. cylinder. Longer settling of sludge from this tank did not materially decrease the sludge volume in warm weather, but sludge from the other three aerating tanks showed a further decrease in volume after one hour. In cold weather sludge from all tanks compacted considerably after one hour. Increasing viscosity due to lowered temperature was probably responsible for these results.

The ratio of sludge returned to sewage treated is important as it determines to a considerable degree the aeration period. A relatively large amount of returned sludge is very undesirable but cannot be avoided with hopper bottom tanks, especially in cold weather when the sludge settles slowly. The volumetric per cent of sludge in the sludge return and aerating tanks depends upon the moisture content of the sludge, which in turn depends upon its biological condition and the temperature.

During the summer runs, July 11 to Aug. 28, the sludge returned averaged about 50 per cent of the sewage treated. During Run 6, Aug. 29 to Sept. 16, the sludge settled very slowly, 70 per cent of the sewage flow being returned, giving 48 per cent in the aerating tanks. This slow settling must have been due to the poor condition of the sludge, as the temperatures of the sewage and air were still almost as high as during the previous run.

As colder weather set in, the sludge acquired slower settling properties, which resulted in the return of an excessive amount of sludge, averaging 67 per cent of the sewage flow throughout Runs 7, 8 and 9. During Runs 10 and 11 less sludge was returned, averaging 51 percent, but an excessive amount of air was used, averaging 6.0 cu. ft. per gal. of sewage. These results demonstrated that a fast-settling sludge can be developed in cold weather by applying an excessive quantity of air.

From Dec. 16, 1916, to March 26, 1917, Runs 12 to 15, the plant was operated primarily to obtain clarification, producing an effluent of low stability. The sludge settled very slowly during this period, the worst condition occuring during Run 13, when 93 percent of sludge was returned.

## SUMMARY, SLUDGE NOT RE-AERATED.

The foregoing results indicate the main features of operation under summer and winter conditions, with no re-aeration or resettling of sludge.

The aeration period necessary to obtain a stable effluent in summer was approximately 9 hours, with a corresponding settling period of approximately 1.5 hour. From 48 to 76 per cent of the sewage flow was returned as sludge, the normal being approximately 60 per cent. The volumetric percentage of sludge in the aerating tanks varied from 19 to 48 per cent, varying roughly in proportion to the percentage returned, but also affected by the condition of the sludge. A poorly activated sludge settles slowly, so that the volumetric amount may vary considerably from day to day.

The air requirement under summer conditions varied from 3.27 to 4.41 cu. ft. per gal. of sewage, the normal being approximately 3.5 cu. ft. per gal., corresponding to a rate of 0.34 cu. ft. per sq. ft. surface area per min.

Under winter conditions a stable effluent could not be obtained without the application of an excessive quantity of air. Operation was adjusted to produce a clarified effluent at as low an air consumption as possible, consistent with a well-activated sludge.

Aeration periods varied from 7 to 11 hours, with the normal at approximately 9 hours. Settling periods, with tank D used in place of tank 7 in Runs 9—12 inclusive, varied from 1.1 to 1.3 hour, securing better results than with longer periods using tank 7. Tank 8 was used in Runs 13 to 15 inclusive, with settling periods from 1.3 to 2.2 hours. This tank did not prove long enough to compare fairly the efficiency of horizontal flow settling tanks with vertical flow.

The air requirement under winter conditions was approximately 4.0 cu. ft. per gal. at a rate of 0.38 cu. ft. per sq. ft. surface area per min. During Run 11, the air was increased to 6.5 cu. ft. per gal., but even with this excessive quantity of air the average relative stability was only 27. In Run 14, the air consumption was reduced to 3.2 cu. ft. per gal. with no marked change in the quality of the effluent, but it is doubtful if the sludge could be kept in good condition continuously if this low rate were continued and the sludge not re-aerated.

## SECOND PERIOD, MARCH 27 TO NOVEMBER 14, 1917.

## RE-AERATION AND RESETTLING OF SLUDGE.

In March, 1917, the activated sludge plant was remodeled (Chapter II), so that the sludge could be re-aerated and resettled before return to the aeration tanks. During the major period, March 27 to November 14, 1917, the following points were investigated:

(1) Economies effected by re-aeration and resettling.

(2) The effect of preliminary screening, with a comparison of 20 and 30 mesh screens.

(3) The efficiency of settling tanks of various designs.

(4) Filter pressing of sludge.

RECONSTRUCTION OF PLANT. Tanks 3 and 4 were connected in series, with the outlet end of tank 4 connected with the inlet of the settling tank. Tanks 5 and 6 were conneced in series, with the outlet end of tank 6 remodeled for use as a secondary settling tank. This tank was used as a combined sludge aeration and settling tank. The piping was so arranged that sludge from the main settling tank could be pumped either to tank 5 or 6. The re-aerated and re-settled sludge from tank 6 was returned to the sewage aeration tanks (tanks 3 and 4) by means of an air lift. After several runs, tank 5 was used for sludge storage in connection with experiments on filter pressing. The piping of the plant was connected so that the excess sludge could be removed from the main settling tank or from the re-aerated sludge settling tank. Tank D was used as the main settling tank. Later the rectangular settling tank 8 was remodeled and fitted with inclined baffles (Fig. 15). This was used for several runs.

AIR MEASUREMENTS. Aeration tanks 3 and 4 and sludge re-aeration tank 6 were fitted with 3 by 1½ inch Venturi meters, to determine the air consumption used for sludge re-aeration, as well as the total air consumption.

FILTROS PLATES. The surface of all filtros plates was thoroughly scrubbed before starting aeration. After the plant started, the air pressure varied between 17 and 17.5 ft. of water, or about 2 feet more water head than during any previous period. This increase in pressure was occasioned either by clogging of the

fitros plates or air pipes. On April 19, 1917, the 1½ in. air pipes feeding the filtros plates were cleaned by flushing with water under pressure. Considerable iron rust was removed. The air pressure then dropped to about 13 ft. of water. The variation in air pressure is noted in Table 42.

**TABLE 42**

VARIATIONS IN AIR PRESSURE ON FILTROS PLATES

| Period in 1917 | Air Pressure Feet Water |
|---|---|
| Mar. 27 to April 22 | 17.0 |
| April 23 to May 30 | 13.3 |
| May 31 to July 1 | 13.2 |
| July 2 to July 31 | 14.1 |
| Aug. 1 to Aug. 31 | 15.1 |
| Sept. 1 to Sept. 30 | 14.7 |
| Oct. 1 to Oct. 21 | 15.7 |
| Oct. 22 to Nov. 14 | 16.5 |

A marked increase in air pressure occured, equivalent to a loss of head of 3.2 ft. (of water) during the period April 23, 1917 to Nov. 14, 1917. This loss of head was due primarily to clogging of the air pipes feeding the filtros plates, caused by rust and scale collecting at elbows or similar fittings.

OPERATING DATA. March 27 to November 14, 1917. The operating results from Mar. 27, 1917 to Nov. 14, 1917 were divided into ten runs which varied according to the sewage aeration period, the sludge re-aeration period, or the settling period. From March 27 to May 3, 1917, the day sewage was screened through a 30 mesh rotary screen. The screen was not operated from May 4 to 20, 1917. From May 21 to Nov. 14, 1917, a 20 mesh screen was used.

The sludge from the main settling tank was pumped continuously to the sludge re-aeration tank, aerated for a definite period and then resettled. The concentrated re-aerated sludge was returned by means of an air lift to the sewage aeration tanks.

METHOD OF CALCULATING AERATION AND SETTLING PERIOD. To make results obtained with sludge re-aeration directly comparable with those when sludge was not re-aerated, the aeration and settling periods must be calculated on the same basis in each case.

The aeration period of the sewage is calculated on the flow of sewage plus returned sludge into the total volume of aeration tanks. The aeration period of the re-aerated sludge is calculated

on the total volume of sludge removed from the main settling tank into the total volume of the re-aeration tank. As a certain proportion of effluent is removed from the resettling tank, the re-aeration period must be multiplied by a factor equivalent to the proportion this re-aerated effluent is of the sewage treated. This "weighted period" must be added to the period in the aeration tanks, in order to obtain a direct comparison with the results obtained when sludge was not re-aerated.

The settling period is the weighted average of (1) the period calculated for the volume of effluent from the primary settling tank into the settling capacity of the tank (end of inlet pipe to flow line), and (2) the settling period of the re-aerated effluent, calculated from the volume of the effluent from the re-settling tank into the settling capacity of the tank (volume above hopper). The analyses of sewage are weighted according to the relative volumes of liquor settled in each tank.

AIR. The air supply was materially reduced on Sunday, with the comparatively weak sewage, and gradually increased from Monday to Saturday. The maximum rate of air was applied either Friday or Saturday. The air was not varied from day to night, although the strength of sewage varied considerably.

## TABLE 43

OPERATING DATA, MARCH 27–NOVEMBER 14, 1917

FLOWS AND DETENTION PERIODS

| No. of Run | Period 1917 | Sewage Treated Gallons per Day | Ratio of Flows | | Effluent Primary Settling Tank Gal. per Day | Effluent Re-aerated Sludge Gal. per Day | Ratio Effluent Re-aerated Sludge to Sewage | Aeration Periods, Hours | | | Settling Period, Hours | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sludge to Sewage | Re-aerated Sludge to Sewage | | | | Sewage | Sludge | Total Weighted for Volume of Re-aerated Effluent | Primary Settling Tank | Secondary Settling Tank | Total Weighted Average |
| 16 | March 27 to April 22 | 64,200 | 0.80 | 0.41 | 39,200 | 25,000 | 0.39 | 5.42 | 3.70 | 6.9 | 2.06 | 1.54 | 1.9 |
| 17 | April 23 to May 30 | 46,700 | 0.92 | 0.51 | 27,500 | 19,200 | 0.41 | 7.14 | 4.40 | 8.9 | 3.07 | 2.00 | 2.7 |
| 18 | May 31 to July 1 | 66,300 | 0.79 | 0.44 | 43,100 | 23,200 | 0.35 | 5.20 | 3.66 | 6.5 | 1.90 | 1.66 | 1.8 |
| 19 | July 2 to July 22 | 66,940 | 0.69 | 0.40 | 47,500 | 19,440 | 0.29 | 5.40 | 4.10 | 6.6 | 1.80 | 2.00 | 1.9 |
| 20 | July 23 to Aug. 8 | 63,900 | 0.77 | 0.41 | 40,900 | 23,000 | 0.36 | 5.60 | 3.90 | 7.0 | 2.10 | 1.67 | 2.0 |
| 21 | Aug. 9 to Aug. 21 | 70,050 | 0.74 | 0.39 | 45,600 | 24,450 | 0.35 | 5.20 | 3.70 | 6.5 | 1.90 | 1.57 | 1.8 |
| 22 | Aug. 22 to Sept. 23 | 69,500 | 0.71 | 0.37 | 46,000 | 23,500 | 0.34 | 5.40 | 3.84 | 6.7 | 1.96 | 1.63 | 1.8 |
| 23 | Sept. 24 to Oct. 12 | 70,940 | 0.65 | 0.31 | 46,600 | 24,340 | 0.34 | 5.40 | 4.10 | 6.8 | 1.84 | 1.58 | 1.75 |
| 24 | Oct. 13 to Oct. 21 | 77,400 | 0.66 | 0.33 | 52,000 | 25,400 | 0.32 | 4.90 | 3.70 | 6.1 | 1.69 | 1.51 | 1.6 |
| 25 | Oct. 22 to Nov. 14 | 69,800 | 0.82 | 0.43 | 42,600 | 27,200 | 0.39 | 5.00 | 3.30 | 6.3 | 1.07 | 1.41 | 1.2 |

**TABLE 44**

OPERATING DATA, MARCH 27 TO NOVEMBER 14, 1917

TEMPERATURES, AIR CONSUMPTION, DETENTION PERIODS

| No. of Run | Period of Operation 1917 | No. of Days | Temperature, Degrees F. | | | | Sewage Treated Gallons | Air, Cu. Ft. per Gal. | | | Total Aeration Period Hours | Total Settling Period Hours |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Atmos. | Comp. Air | Inf. | Eff. | | Sewage Aerated | Re-aerated Effluent | Sewage Treated Weighted | | |
| 16 | March 27 to April 22 | 27 | 45 | 97 | 69 | 62 | 1,734,600 | 3.29 | 2.72 | 4.35 | 6.9 | 1.9 |
| 17 | April 23 to May 30 | 38 | 51 | 86 | 71 | 66 | 1,775,100 | 3.09 | 2.60 | 4.15 | 8.9 | 2.7 |
| 18 | May 31 to July 1 | 32 | 64 | 98 | 74 | 75 | 2,122,000 | 2.30 | 3.48 | 3.52 | 6.5 | 1.8 |
| 19 | July 2 to July 22 | 21 | 69 | 108 | 81 | 80 | 1,405,700 | 2.65 | 3.65 | 3.71 | 6.6 | 1.9 |
| 20 | July 23 to Aug. 8 | 17 | 77 | 114 | 86 | 84 | 1,086,300 | 2.77 | 3.00 | 3.85 | 7.0 | 2.0 |
| 21 | Aug. 9 to Aug. 21 | 13 | 71 | 111 | 84 | 83 | 910,600 | 2.50 | 2.51 | 3.38 | 6.5 | 1.8 |
| 22 | Aug. 22 to Sept. 23 | 33 | 65 | 103 | 83 | 80 | 2,294,200 | 2.39 | 2.41 | 3.21 | 6.7 | 1.8 |
| 23 | Sept. 24 to Oct. 12 | 19 | 54 | 87 | 80 | 75 | 1,347,900 | 2.44 | 2.56 | 3.31 | 6.8 | 1.7 |
| 24 | Oct. 13 to Oct. 21 | 9 | 47 | 90 | 75 | 69 | 696,500 | 2.49 | 2.90 | 3.42 | 6.1 | 1.6 |
| 25 | Oct. 22 to Nov. 14 | 24 | 43 | 86 | 74 | 68 | 1,676,500 | 2.62 | 2.62 | 3.64 | 6.3 | 1.2 |

## TABLE 46

ACTIVATED SLUDGE

Analytical Data Showing Reduction in Certain Constituents

March 27 to November 14, 1917

| No. of Run | Total Suspended Matter | | | Nitrogen as | | | | | | | | Aver. Diss. Ox. | B. O. C. | Rel. Stab. Percent | Air Cu. Ft. per Gal. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Organic | | | Free Ammonia | | | Nitrites | Nitrates | | | | |
| | Influent | Effluent | Percent. Reduction | Influent | Effluent | Percent Reduction | Influent | Effluent | Percent Reduction | | | | | | |
| 16 | 273 | 25 | 90.8 | 37 | 11 | 70.3 | 11 | 18 | −63.6 | 0.39 | 0.20 | 1.7 | 44 | 38 | 4.35 |
| 17 | 331 | 31 | 90.7 | 41 | 9 | 78.1 | 13 | 17 | −30.8 | 0.46 | 0.43 | 1.7 | 45 | 45 | 4.15 |
| 18 | 271 | 18 | 93.4 | 37 | 6.7 | 81.9 | 13 | 11 | 15.4 | 0.76 | 1.38 | 1.7 | 60. | 54 | 3.52 |
| 19 | 284 | 24 | 91.6 | 31 | 6 | 80.7 | 14 | 12 | 14.3 | 1.10 | 0.55 | 2.0 | 42 | 48 | 3.71 |
| 20 | 250 | 33 | 86.8 | 31 | 8 | 74.2 | 13 | 5 | 61.5 | 2.46 | 1.59 | 2.2 | 45 | 66 | 3.85 |
| 21 | 264 | 20 | 92.4 | 25 | 4 | 84.1 | 15 | 5 | 66.7 | 2.02 | 2.89 | 2.3 | 37 | 76 | 3.38 |
| 22 | 322 | 25 | 92.3 | 25 | 3 | 88.0 | 14 | 5 | 64.3 | 0.57 | 4.90 | 2.1 | 35 | 89 | 3.21 |
| 23 | 322 | 16 | 95.1 | 34 | 3 | 91.2 | 12 | 5 | 58.3 | 0.31 | 5.80 | 2.8 | 17 | 95 | 3.31 |
| 24 | 359 | 18 | 95.0 | 32 | 5 | 84.3 | 11 | 9 | 18.2 | 0.75 | 1.77 | 1.9 | 25 | 60 | 3.42 |
| 25 | 305 | 28 | 90.8 | 36 | 6 | 83.4 | 11 | 13 | −18.2 | 0.93 | 0.71 | 3.0 | 25 | 59 | 3.64 |

AERATION PERIODS. The results obtained during this period (Mar. 27 to Nov. 14, 1917) are in general representative of summer conditions. During April, May, October and November, however, temperatures were lower and the results were inferior to those obtained during July, August and September.

During the ten runs into which the period was divided, no changes were made in the general flow-scheme outlined above, but changes were made in the screen and in the primary settling tanks during the course of the tests. The sewage flow was at the same general rate as previously used with the four aeration tanks in series, the same volume of sewage being handled in three tanks with re-aeration as previously in four without re-aeration.

Operation data are shown in Tables 43 and 44. The aeration period of the sewage averaged around 5.5 hours during all runs with exception of Run 17, when the large blower was being repaired. To supply a reasonable amount of air with the small blower, it was found necessary to lengthen the period to 7.1 hours. The period of aeration of the sludge was likewise lengthened to 4.4 hours during this run, although in other runs it averaged about 3.8 hours. The screen was not operated during most of Run 17 as it was being repaired and refitted with a 20-mesh brass wire screen.

From Run 18 through Run 22, May 31 to Oct. 21, 1917, sewage aeration periods averaged 5.4 hours, sludge aeration periods 3.8 hours, the weighted average being 6.7 hours. Air was kept at 3.5 cu. ft. per gal.

The last two runs, 24 and 25, from Oct. 12 to Nov. 14, were almost identical, with a total sewage aeration period around 4.9 hours, sludge aeration 3.5 hours, air consumption 3.5 cu. ft. per gal. Tank 8, the vertical inclined tank (described later) was used during all of Run 25 and part of Run 24. The total settling period was reduced to 1.2 hours with this tank, as compared with an average around 1.8 hours with tank D.

The amount of screenings recovered during Run 24 increased markedly. A 1-inch mesh screen was therefore placed in the inlet box to the settling tank during Run 25, in order to catch screenings which might clog the 2-inch sludge pipes.

ANALYTICAL RESULTS. Analytical results for the ten runs are given in Tables 45 and 46. The samples were divided into day, night and Sunday composites. A theoretical average was computed for the combined effluent in direct proportion to the

volumes from the main settling tank and the re-aerated sludge settling tank.

The relation of the general (day, night and Sunday combined) average to the day average is shown in the following comparison of crude sewage.

| Results in Parts per Million | | | |
|---|---|---|---|
| Average | Total Suspended Solids | Total Organic Nitrogen | Ammonia Nitrogen |
| General | 250 to 359 | 25 to 41 | 11 to 15 |
| Day | 376 to 573 | 37 to 58 | 14 to 23 |

In cold weather the ammonia nitrogen was greater in the effluent than in the crude sewage. As the temperature increased, the increase in ammonia became less marked until the transition temperature, at about 75 deg. Fahr., where the ammonia in the effluent began to be reduced below that in the influent. Nitrification proceeded very slowly in cold weather, a marked slowing up being noted in Run 24, when the temperature of the effluent dropped to 69 deg. Fahr. from 76 deg. Fahr. on the previous run.

The reduction in total suspended matter was not a function of the temperature, but of the operation of the settling tanks. Fine particles of sludge passed over in the effluent which the settling tank would remove at a slower rate. The total suspended matter of the combined effluent averaged from 16 to 33 p. p. m., corresponding to a reduction of from 87 to 95 per cent.

The reduction of organic nitrogen was fairly high at all times, but with a greater reduction in warmer weather. The general average of the total organic nitrogen of the combined effluent varied from 3 p. p. m. to 11 p. p. m., with a reduction varying from 70 to 91 per cent.

The ammonia nitrogen increased 64 per cent in Run 16 with the sewage temperature at 69 deg. Fahr., whereas the greatest reduction was 67 per cent in Run 21 with the temperature of the sewage at 84 degrees.

In the effluent, nitrogen as nitrites and nitrates varied from 0.59 p. p. m. to 6.21 p. p. m.; dissolved oxygen from 1.7 to 3.0 p. p. m.; biologic oxygen consumed from 17 to 60 p. p. m.; and the average relative stability from 38 to 95 per cent.

The effluent from the main settling tank was not as good as that from the sludge re-aeration settling tank, particularly in the

nitrification obtained and relative stability. The total suspended matter of the main settling tank was usually lower, because of the better efficiency of the settling tank. In the effluent from the sludge re-aeration settling tank, the organic nitrogen was slightly lower, the ammonia nitrogen was considerably lower, the nitrites, nitrates and relative stability were considerably higher, and the biochemical oxygen demand was slightly lower. Thus the effluent from the sludge re-aeration settling tank improved the quality of the main effluent.

SETTLING TANKS. During this period of operation, three types of settling tanks were used, as follows:

1. Vertical flow (tank D) from March 27 to Oct. 22, Runs 16 to 24 inclusive.
2. Vertical horizontal flow (tank G), sludge resettling tank, all runs.
3. Vertical inclined flow (tank 8, remodeled), Oct. 23 to Nov. 14, Run 25.

TANK D. Tank D proved larger than required to handle the flows from the runs with re-aerated sludge, in which the volume of returned sludge was decreased notably. The detention periods varied from 1.69 to 3.07 hours, the latter being much above the settling period required. The normal period was around 1.9 hours. This tank treated from 500 to 660 gal. of sewage per sq. ft. per 24 hr. (calculated on volume of effluent). The normal was approximately 575 gal. per 24 hr.

TANK 6. This tank was of the vertical-horizontal flow type, 6 ft. 6 in. long by 6 ft. wide and 12 ft. deep. The inlet trough extended across the entire width of the tank. The sewage had a vertical flow of 5 ft. and a horizontal flow of 5½ ft. The hopper bottom had slopes of 2 vertical to 1 horizontal on sides, and 1.5 vertical to 1 horizontal in corners. The sludge was removed from the hopper bottom by means of an air lift on the outside of the tank. This tank gave good results, without trouble from septic sludge, operating successfully with detention periods from 1.41 to 2.00 hours, being normally approximately 1.6 hours, treating from 500 to 650 gal. of sewage per sq. ft. per 24 hours (based on volume of effluent), the normal being approximately 600 gal. per 24 hr. The liquor entering this tank was sludge from the main settling tank. This contained considerably more material in suspension than the aerated sewage—sludge mixture and settled

much more slowly with quiescent settling. Hence a tank of this design could probably be operated at a higher comparative rate than the vertical flow type with the same influent liquor.

TANK 8 (REMODELED). Tank 8 (Fig. 15) was remodeled into a special design vertical-inclined type of tank, after many experiments on settling the sewage-sludge mixture in inclined cylinders. (See Chapter 8). Only part of tank 8 was used for settling, it being divided into three equal sections by means of wooden baffles, each 5 ft. by 3 ft. in section, and 10 ft. vertical depth. Two hoppers were constructed in the bottom of each section for removing the sludge. Each section was practically an independent settling tank, containing a separate inlet pipe 6 ft. below the top of tank, and a separate effluent trough. The baffles were originally placed at 30 degrees, but were changed to 60 degrees because the sludge adhered to the baffles and became septic. The sides of the sludge hoppers were also at 60 degrees to the horizontal. Either one, two or three of the sections, could be used, thus making it possible to determine the maximum rate of operation for this type of tank. The sludge was drawn off through 2-inch pipes in the bottom of each hopper. At first the sludge pump drew more sludge from the hopper nearest the pump, thereby permitting the sludge in the other hopper sections to become septic. This was remedied by changing the sludge draw-off pipe (Fig. 15). This tank gave excellent results in Run 25 while operating with a flow of 950 gal. (effluent) per sq. ft. per 24 hr. In additional tests satisfactory results were obtained with rates as high as 1400 gal. (effluent) per sq. ft. per 24 hr.

A flow test (with soda ash) was made on this tank on Oct. 20, 1917 (Fig. 19), the volume of effluent from the tank being 61,100 gal. per 24 hr., giving a settling rate of 1340 gal. per sq. ft. per 24 hr. The flow curves are very sharp showing that practically the entire settling volume of the tank is effective. The curves indicate that the actual settling period was 25 to 30 minutes, the theoretical, based on volume of effluent alone, 58 minutes. The actual sludge detention period was only 5 to 10 minutes. Probably with hopper bottom tanks of this type, the ratio of the sludge capacity to settling capacity should be greater. The ratio was 1 to 2.3 in this tank.

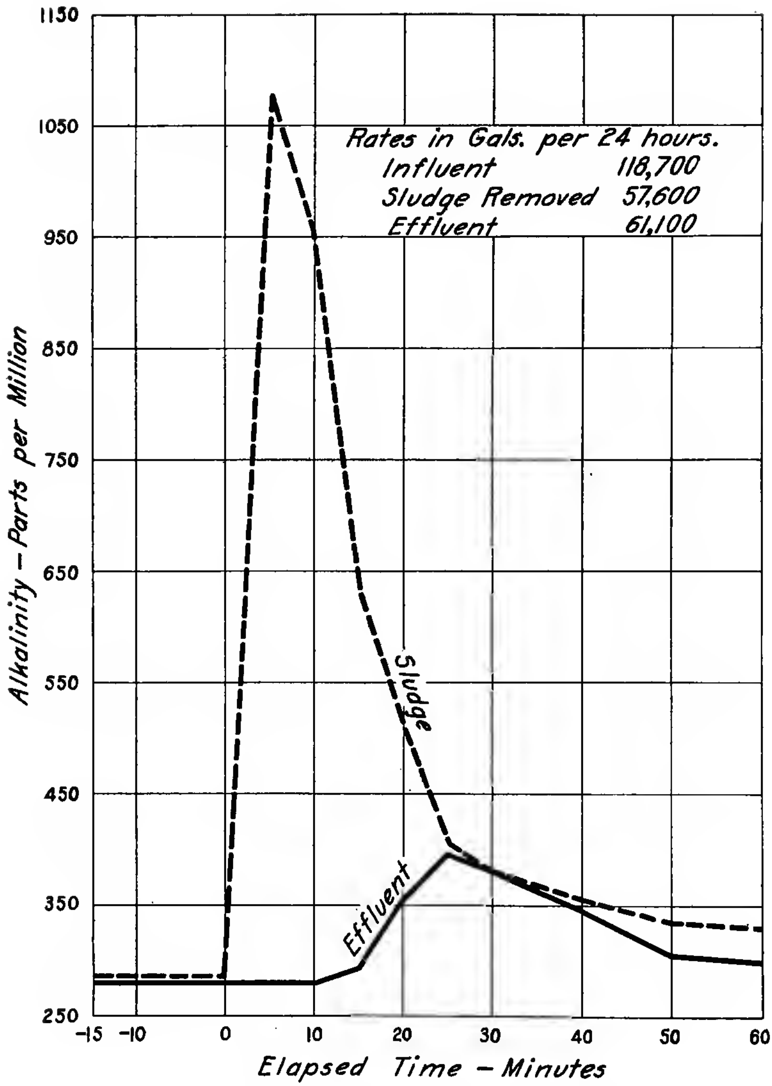


Fig. 19. Flow Test on Settling Tank 8, Remodeled.

COMPARISON OF TANKS. The results indicate that the special design vertical-inclined flow type can handle 50 to 100 percent more sewage than the other types of tanks tested.

The slopes of hopper bottom tanks should be about 2 vertical to 1 horizontal, to avoid trouble from sludge adhering to the sides and becoming septic. With such slopes, single hopper tanks would be of great depth or else shallower tanks could be built with several hoppers. With more than one hopper or sludge draw-off in a tank, more supervision is required, to remove equivalent amounts of sludge continously from each section. In hopper bottom tanks, the sludge is not removed at the same rate from the entire cross-section. Flow tests clearly showed that most of the sludge was taken directly down the center of the hopper and comparatively little from the sides.

With flat bottom tanks, two general methods of sludge removal can be used, both using mechanical contrivances involving moving parts. One collects all the sludge at a common point, for removal by an air lift or pump. The other comprises a movable siphon or air lift traversing the entire bottom of the tank. The removal of sludge should proceed from the entire bottom at a regular rate because sludge that is not continuously removed will become septic in a short time.

The advantages of flat bottom tanks are as follows:

1. Tanks can be constructed of comparatively shallow depths.

2. A more concentrated sludge is obtained, thus permitting smaller units for removing the sludge and smaller sludge return channels. The effective capacity of the aeration tanks is increased.

On the other hand mechanical appliances are required, which necessitate additional supervision and more power is required to operate the mechanical apparatus.

SLUDGE RATIO. The ratio of sludge return to sewage flow depends primarily upon the concentration of the sludge returned. With a definite amount of activated sludge in the aeration tanks, concentration of sludge volume appears advantageous to reduce the requirements of power for pumping and the number of tanks for aeration. Re-aeration and resettling of the sludge reduced the water content greatly. From July 2, 1916, to March 27, 1917, with the direct return of sludge to the aeration tanks, 63 percent of the average sewage flow was returned as sludge, giving an average of 38.5 percent (volumetric) of sludge in the

mixture after settling 1 hour. From Mar. 27 to Nov. 14, 1917, with re-aerated and resettled sludge, only 40 percent of the average sewage flow was returned as sludge with an average of 28.5 percent of sludge in the mixture after settling 1 hour. If sludge had been returned directly to the aerating tanks without re-aerating and resettling, 76 per cent of the sewage flow would have been returned, giving 43 percent of sludge in the aeration tanks. During the later period the sludge removed from the primary settling tank was rather liquid and not well activated, due to the short aeration period.

The volume of aeration tanks necessary for a given aeration period would be 163 percent of the sewage flow in the first period stated, but only 140 percent of the sewage flow in the second period, when sludge was resettled. During the second period the average ratio of the sludge from the main settling tank to that from the re-aerated settling tank was 1.90, a reduction of 47.5 per cent in volume. For each 100 gallons of sludge removed from the main settling tank 52.5 gallons of concentrated sludge was returned to the aeration tanks and 47.5 gallons of purified effluent discharged. On the other hand, greater settling capacity is required when the sludge is resettled. During the first period, when sludge was not re-aerated, settling periods of from 1.1 to 1.5 hours were sufficient. During the second period, the total period, weighted for the relative amounts treated in each tank, was around 1.8 hours.

## SUMMARY, SLUDGE RE-AERATED AND RESETTLED.

The period of operation from March 27 to November 14, 1917 did not include winter conditions. The results, however, may be compared with the summer results of the previous period.

Re-aeration of the sludge effected a great reduction in volume of sludge returned. More sewage was treated in three aeration tanks than previously in four. Aeration periods averaged around 5.3 hours in the aeration tanks and 3.8 hours in the sludge tank, the weighted average being approximately 6.6 hours.

Average settling periods were 1.8 hours in the primary tank, 1.6 hours in the re-settling tank, a total of 1.7 hours when weighted for the relative volumes of effluent discharged from each tank.

Air consumption (excluding runs 16 and 17) was approximately 2.5 cu. ft. per gal. of sewage, and 2.9 cu. ft per gal. of re-aerated effluent, a weighted total of 3.5 cu. ft. per gallon of sewage treated.

The effluent from the main settling tank, averaging 65 percent of the total, was of low stability. The effluent from the re-aeration tank was of higher stability, however. The combined effluent was of fair stability, although not as stable on the whole as the effluent obtained during the first period of operation, when the sludge was not re-aerated.

Operation of three types of settling tanks indicated that the vertical-horizontal flow type used for re-settling sludge was very satisfactory, but that even better results could be obtained with a vertical-inclined flow type.

## THIRD PERIOD, NOV. 16, 1917 TO FEB. 12, 1918.

From Nov. 16, 1917 to Feb. 12, 1918, during remodelling, several tests were made with two aeration tanks (tanks 3 and 4) and one settling tank (tank 8).

Four runs were made with a constant rate of flow of sewage. The sludge from the settling tank was returned directly to the sewage-aeration tanks without re-aeration or re-settling.

AERATION PERIODS AND ANALYTICAL RESULTS. Aeration periods and operating data are shown in Table 47, the analytical results in Tables 48 and 49. The aeration period during the first two runs was shortened by the excessive amount, 93 percent, of sludge returned. During the last two runs the volume of returned sludge was reduced to 63 percent, increasing the aeration period to 8.5 hours.

The quantity of air used averaged around 4.3 cu. ft. per gal., slightly higher than the 4.0 cu. ft. found necessary during the winter of 1916-17.

The ratio of sludge returned to sewage flow was excessive during the first two runs due to the use of only two sections of the settling tank. While the sludge settled very rapidly in this tank, at the rate of 1300 gal. (effluent) per sq. ft. per 24 hr., it was very light and flocculent and a large amount was removed to prevent it from being discharged with the effluent. During the last two periods, three hoppers were used, settling the sludge at the rate of 900 gallons per sq. ft. per 24 hr. This reduced the returned sludge to 63 percent of the sewage flow, and gave more satisfactory results than were obtained during the preceding runs.

The effluent throughout this period showed little nitrification and low stabilities, because of winter temperatures, the winter of 1917-18 being unusually severe, although actual temperatures

# TABLE 47

ACTIVATED SLUDGE. OPERATING DATA

November 16, 1917 to February 12, 1918

| No. of Run | Period of Operation 1917–18 | No. of Days | Temperature Degrees F. | | | | Flow Gallons per Day | | Ratio of Flow to Sewage | Aeration Period Hours | Settling Period Hours | Air Cu. Ft. per Gal. Sewage | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Atmos. | Comp. Air | Influent | Effluent | Sewage | Sludge | | | | | |
| 26 | Nov. 16 to 25, inc. | 10 | 43 | 75 | 75 | 68 | 35,680 | 33,160 | 0.93 | 7.3 | 0.98 | 4.50 | |
| 27 | Nov. 28 to Dec. 19, inc. | 22 | 24 | 62 | 69 | 62 | 36,800 | 33,700 | 0.92 | 7.1 | 0.95 | 4.62 | |
| 28 | Dec. 20 to Jan. 31, inc. | 43 | .... | 54 | 62 | 53 | 36,500 | 22,450 | 0.62 | 8.5 | 0.96 | 4.16 | |
| 29 | Feb. 1 to 12, inc. | 12 | .... | 56 | 65 | 55 | 35,800 | 23,070 | 0.65 | 8.4 | 0.98 | 4.11 | |

NOTE:—Aeration Period—Aeration Period Computed from Total Flow and Total Volume of Aeration Tanks.
Settling Period—Settling Period Computed from Sewage Flow only to the Settling Tank and the Settling Volume of Tank.

## TABLE 48

ACTIVATED SLUDGE. SUMMARY OF ANALYTICAL DATA

November 16, 1917 to February 12, 1918

| No. of Run | Period of Operation | Average | Influent: Parts per Million | | | Effluent: Parts per Million | | | | | | | | | Aver. Rel. Stab. Percent | Temp. Deg. F. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Susp. Matter | Nitrogen as Organic N. | Nitrogen as Free $NH_3$ | Total Susp. Matter | Nitrogen as Organic N. | Nitrogen as Free $NH_3$ | Nitrogen as Nitrites | Nitrogen as Nitrates | Turb. | D. O. | B. O. C. | | | |
| 26 | Nov. 16 to Nov. 25, 1917 | Day | 450 | 54 | 13 | 22 | 6.1 | 20 | 0.31 | 0.21 | 11 | 3.7 | 19 | | 61 | 68 |
| | | Night | 262 | 56 | 11 | 28 | 6.0 | 20 | 0.46 | 0.25 | 11 | 3.7 | 19 | | 70 | 68 |
| | | Sunday | 420 | 27 | 11 | 22 | 8.2 | 17 | 1.25 | 0.65 | 10 | 6.2 | 14 | | 97 | 66 |
| | | D & N & S | 381 | 49 | 12 | 24 | 6.5 | 19 | 0.55 | 0.31 | 11 | 4.2 | 18 | | 71 | 68 |
| 27 | Nov. 28 to Dec. 19, 1917 | Day | 509 | 73 | 15 | 27 | 8.1 | 21 | 0.64 | 0.45 | 18 | 3.1 | 30 | | 47 | 62 |
| | | Night | 260 | 51 | 9 | 49 | 10.0 | 20 | 0.72 | 0.54 | 21 | 3.7 | 33 | | 49 | 61 |
| | | Sunday | 147 | 28 | 9 | 22 | 11.9 | 19 | 0.53 | 0.71 | 22 | 7.1 | 28 | | 70 | 57 |
| | | D & N & S | 370 | 59 | 13 | 34 | 9.3 | 21 | 0.65 | 0.52 | 19 | 3.9 | 31 | | 51 | 62 |
| 28 | Dec. 20, 1917 to Jan. 31, 1918 | Day | 483 | 65 | 15 | 42 | 10.0 | 22 | 0.13 | 0.43 | 16 | 2.5 | 41 | | 35 | 54 |
| | | Night | 236 | 34 | 8 | 46 | 10.2 | 20 | 0.12 | 0.53 | 14 | 3.1 | 38 | | 39 | 52 |
| | | Sunday | 181 | 32 | 8 | 51 | 9.1 | 20 | 0.23 | 0.64 | 13 | 4.5 | 27 | | 56 | 53 |
| | | D & N & S | 343 | 48 | 11 | 45 | 9.9 | 21 | 0.15 | 0.50 | 15 | 3.1 | 38 | | 41 | 53 |
| 29 | Feb. 1 to Feb. 12, 1918 | Day | 419 | 62 | 15 | 34 | 10.0 | 24 | 0.08 | 0.32 | 23 | 2.2 | 21 | | 37 | 55 |
| | | Night | 314 | 38 | 11 | 27 | 7.3 | 22 | 0.20 | 0.32 | 18 | 2.4 | 20 | | 43 | 55 |
| | | Sunday | 199 | 30 | 12 | 31 | 6.0 | 28 | 0.72 | 0.68 | 10 | 5.3 | .... | | 76 | 52 |
| | | D & N & S | 347 | 48 | 13 | 31 | 8.4 | 24 | 0.23 | 0.38 | 19 | 2.8 | 21 | | 46 | 55 |

## TABLE 49

ACTIVATED SLUDGE. ANALYTICAL DATA SHOWING REDUCTION IN CERTAIN CONSTITUENTS

November 16, 1917 to February 12, 1918

Results in Parts per Million Unless Otherwise Stated

| Period | Total Suspended Matter | | | Nitrogen as | | | | | | Effluent | | | | Average Stability | Air Cu. Ft. per Gal. Sewage | Aeration Period Hours Sewage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Organic | | | Free Ammonia | | | | | | | | | |
| | Inf. | Eff. | Percent Reduction | Inf. | Eff. | Percent Reduction | Inf. | Eff. | Percent Increase | Nitrites | Nitrates | D. O. | B.O.C. | | | |
| Nov. 16 to Nov. 25, 1917 | 381 | 24 | 93.7 | 49 | 6.5 | 86.8 | 12 | 19 | 58.4 | 0.55 | 0.31 | 4.2 | 18 | 71 | 4.50 | 7.3 |
| Nov. 28 to Dec. 19, 1917 | 370 | 34 | 90.9 | 59 | 9.3 | 84.3 | 13 | 21 | 61.6 | 0.65 | 0.52 | 3.9 | 31 | 51 | 4.62 | 7.1 |
| Dec. 20, '17 to Jan. 31, '18 | 343 | 45 | 87.0 | 48 | 9.9 | 79.4 | 11 | 21 | 91.0 | 0.15 | 0.50 | 3.1 | 38 | 41 | 4.16 | 8.5 |
| Feb. 1 to Feb. 12, 1918 | 347 | 31 | 91.1 | 48 | 8.4 | 82.5 | 13 | 24 | 84.6 | 0.23 | 0.38 | 2.8 | 21 | 46 | 4.11 | 8.4 |

of the effluent were not lower than those recorded during the previous winter. Temperatures of the compressed air were lower in 1917-18 than in 1916-17, however, varying from 54 to 62 deg. Fahr. in 1917-18 and from 60 to 92 deg. in 1916-17.

EFFICIENCY OF INCLINED FLOW SETTLING TANK. The inclined-flow settling tank operated satisfactorily with a detention period around 0.95 hour as compared with the 1.3 to 2.2 hours found necessary with the same tank the preceding winter. This economy in settling space was effected by the superior settling efficiency of the inclined tank. (See Chapter 8). The construction of the inclined baffles was not entirely satisfactory, hence the inclined flow type was not working at its maximum efficiency.

On the other hand the construction of this type of tank necessitates a number of small hoppers, which increase the available settling capacity for a given depth, but require more careful supervision in order to remove sludge uniformly from all hoppers. An individual air lift was needed for almost every hopper. The control of such a large number of air lifts would not be feasible in a large plant. In addition, the construction of a large number of thin inclined baffles would complicate the design of the settling tanks and possibly cause an undesirable loss of head. It would seem that the principle of operation of inclined-flow settling tanks, while novel and interesting theoretically, is not feasible practically, except on a small scale.

COMPARISON OF RESULTS. AERATION VS. RE-AERATION. Aeration was studied both under winter and summer conditions, whereas re-aeration and re-settling were observed only in the spring, summer and fall. A marked difference in quality of effluent was noted in winter as compared with summer, so that similar seasons must be chosen when comparing aeration with re-aeration. Hence only summer results can be compared in these investigations.

The average operating results are summarized (Table 50) during summer conditions in 1916, when the sludge was not re-aerated, and during 1917, when the sludge was re-aerated and re-settled.

**TABLE 50**

OPERATING RESULTS

Aeration vs. Reaeration

| | Aeration Period Hours | Settling Period Hours | Air Cu. Ft. per Gal. | Ratio Sludge Return Sewage | Sewage Treated Gal. per 24-Hr. | Percent Sludge 33* | Period Compared |
|---|---|---|---|---|---|---|---|
| Aeration, Alone.......... | 9.0 | 1.3 | 3.5 | .60 | 61,000 | ................ | July 2 to Oct. 22, 1916 |
| Re-aeration and Re-settling.......................... | 6.6 | 1.7 | 3.5 | .39 | 68,800 | ................ | Mar.27 to Nov.14,1917 |

*Percent of sludge in volume in aeration tank, after settling 1 hour.

In general a comparable effluent was produced by each method of operation but the effluent from the primary settling tank in 1917 was of low grade. When mixed with the re-settled effluent, however, the quality was improved sufficiently to approximate the other effluent.

The general summary indicates that a saving of approximately 27 percent of aeration tank volume can be obtained with re-aeration and re-settling of the sludge, but that about 30 per cent more settling tank capacity must be provided. As settling periods are much less than aeration periods, a saving of 20 percent in total tank volume may be obtained by re-aeration.

## Chapter VIII.

## SETTLING AND CONCENTRATING ACTIVATED SLUDGE.

The rate of subsidence of activated sludge from Packingtown sewage depends on several factors, the most important being the state of activation, moisture content and temperature. The volumetric percent of sludge in the aerating tanks varies greatly from day to day, depending upon the moisture content of the sludge. The effect of depth of settling tank was investigated under winter conditions.

EFFECT OF DEPTH OF TANK. A series of experiments was made in 1916 in two tanks, each two feet in diameter. One (A) was 19.85 feet deep, the other (B) 9.0 feet deep. Activated sludge from settling tank D was pumped into tanks A and B by means of a ½-in. centrifugal pump. The inlet to the tanks was in the center of the bottom in order to prevent the sludge from settling while filling. It usually settled very evenly, leaving a sharp line of demarcation between the sludge and supernatant liquid. Sludge levels were taken as soon as the tanks were filled, every 15 minutes thereafter for the first hour, every 30 minutes for the next two hours, and hourly thereafter. The results are recorded in Table 51.

Practically all results indicate that the concentration took place more rapidly in the shallow tanks. After settling for as long as 3 hours the volumetric percent of sludge was usually lower in the shallow tank. Several tests were continued for as long as 6 hours with relative results identical with those obtained in 3 hours.

The moisture content of the concentrated sludge was determined usually after 3 hours settling. The results show very little difference between the two tanks, in some cases a more concentrated sludge being removed from the shallow tank. Thickening of the sludge appears to be independent of the depth of the tank.

## TABLE 51

SLUDGE CONCENTRATION

Tank A, 19.5 Ft. Deep. Tank B, 9.0 Ft. Deep

| Date | Percent Sludge, Volumetric | | | | | | | | | | Moisture Content of Sludge | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1916–1917 | 15 Min. | | 30 Min. | | 1 Hr. | | 2 Hr. | | 3 Hr. | | As Filled | | Concentrated Sludge | |
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| Dec. 6 | 87 | .... | 82 | .... | 71 | 69 | 66 | 62 | 63 | 61 | 99.19 | 99.19 | 98.78 | 98.87 |
| 11 | 85 | 67 | 75 | 44 | 60 | 33 | 33 | 31 | 25 | 28 | 99.59 | 99.59 | 99.00 | 99.01 |
| 12 | 82 | 89 | 67 | 61 | 47 | 39 | 35 | 29 | 27 | 22 | 99.43 | 99.43 | 98.85 | 93.86 |
| 13 | 80 | 83 | 72 | 53 | 57 | 31 | 36 | 24 | 28 | 20 | 99.59 | 99.59 | 98.92 | 98.02 |
| Jan. 4 | 95 | 94 | 82 | 72 | 62 | 39 | 40 | 22 | 22 | 19 | 99.66 | 99.66 | 99.09 | 98.83 |
| 5 | 95 | 94 | 87 | 78 | 70 | 44 | 40 | 30 | 35 | 28 | 99.54 | 99.54 | 98.47 | 98.39 |
| 6 | 95 | 94 | 85 | 76 | 75 | 55 | 52 | 37 | 42 | 33 | 99.47 | 99.47 | 97.94 | 98.52 |
| 8 | 87 | 91 | 80 | 76 | 67 | 71 | 42 | 50 | 40 | 44 | 99.53 | 99.53 | 98.25 | 98.32 |
| 9 | 85 | 86 | 82 | 67 | 67 | 47 | 45 | 36 | 39 | 31 | 99.41 | 99.41 | 98.35 | 98.52 |
| 10 | 96 | 100 | 96 | 93 | 91 | 83 | 81 | 60 | 72 | 52 | 99.30 | 99.30 | 98.71 | 98.77 |

# TABLE 52

PERCENT ACTIVATED SLUDGE IN 100 C. C. GRADUATED CYLINDERS AT 90 DEG., VERTICAL, (No. 1) AND 60 DEG. TO HORIZONTAL (No. 2)

| Time of Settling | July 16 Tank 4 | | July 17 Tank 4 | | July 17 Tank 6 | | July 18 Tank 4 | | July 19 Tank 4 | | July 20 Tank 4 | | July 21 Tank 4 | | July 24 Tank 4 | | July 26 Tank 4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minutes | Vert. | 60 Deg. | Vert. | 60 Deg. | Vert. | 60 Deg. | Vert. | 60 Deg. | Vert. | 60 Deg. | Vert. | 60 Deg. | Vert. | 60 Deg. | Vert. | 60 Deg. | Vert. | 60 Deg. |
| 5 | 94 | 76 | 95 | 78 | 97 | 88 | 98 | 96 | 97 | 95 | 97 | 94 | 94 | 90 | 87 | 85 | 95 | 87 |
| 10 | 89 | 63 | 85 | 57 | 89 | 67 | 95 | 89 | 93 | 87 | 95 | 85 | 92 | 81 | 76 | 72 | 90 | 74 |
| 15 | 84 | 52 | 79 | 47 | 79 | 50 | 94 | 83 | 91 | 81 | 92 | 78 | 90 | 75 | 66 | 57 | 83 | 66 |
| 20 | 79 | 46 | 73 | 43 | 61 | 43 | 92 | 76 | 90 | 75 | 90 | 72 | 89 | 68 | 60 | 52 | 79 | 57 |
| 25 | 75 | 42 | 68 | 39 | ---- | ---- | 90 | 71 | 89 | 69 | 88 | 66 | 85 | 63 | 56 | 47 | 75 | 51 |
| 30 | 71 | 38 | 64 | 34 | 57 | 35 | 89 | 66 | 88 | 66 | 86 | 63 | 83 | 59 | 51 | 41 | 69 | 44 |
| 40 | 64 | 35 | 56 | 29 | 50 | 35 | 87 | 60 | 83 | 61 | 82 | 55 | 79 | 52 | 45 | 36 | 63 | 39 |
| 50 | 56 | 31 | 50 | 27 | 49 | 35 | 83 | 56 | 79 | 54 | 78 | 50 | 74 | 48 | 41 | 32 | 56 | 35 |
| 60 | 52 | 31 | 46 | 26 | 47 | 35 | 80 | 40 | 76 | 50 | 74 | 46 | 71 | 45 | 38 | 30 | 52 | 32 |
| 90 | ---- | ---- | ---- | ---- | 45 | 35 | ---- | ---- | ---- | ---- | ---- | ---- | 60 | 40 | ---- | ---- | ---- | ---- |
| 120 | ---- | ---- | 30 | 25 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 50 | 37 | ---- | ---- | ---- | ---- |

NOTE:—Tank 4—Mixture of Sewage and Sludge from Aeration Tanks
Tank 6—Sludge from Sludge Re-aeration Tank

SHOWING TIME REQUIRED FOR EQUAL PERCENT CONCENTRATION OR SETTLING IN A 100 C. C. GLASS CYLINDER AT 60 DEG. TO HORIZONTAL AS THAT OBTAINED IN 1 HOUR WITH CYLINDER AT 90 DEG. (VERTICAL)

| Date | July 16 | July 17 | July 17 | July 18 | July 19 | July 20 | July 21 | July 23 | July 24 | July 26 | July 26 | Nov. 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tank | 4 | 4 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 6 | 4 | 4 |
| Time—Min. | 15 | 16 | 17 | 17 | 19 | 18 | 18 | 23 | 35 | 18 | 24 | 21 |

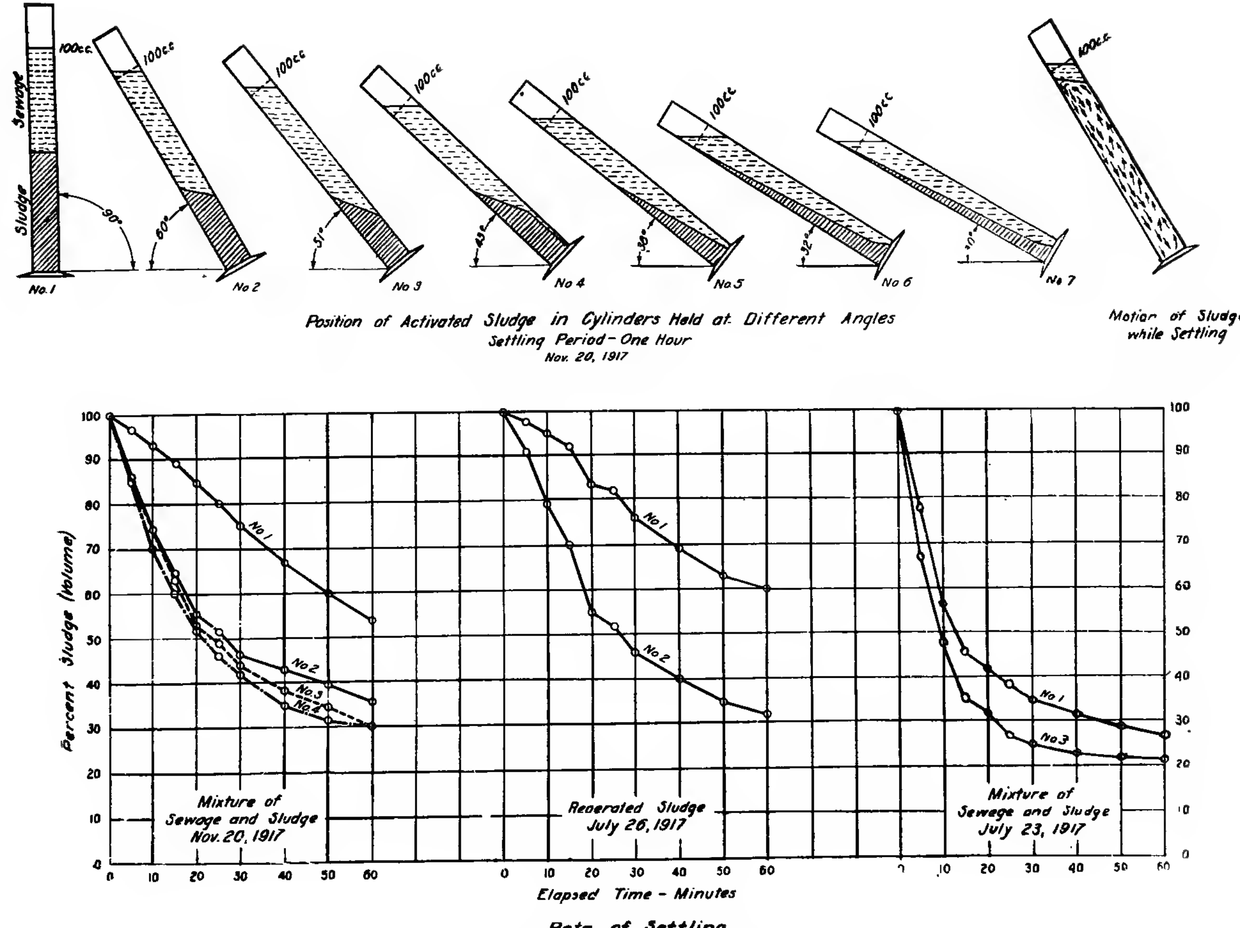


Fig. 20. Effect of Inclination on Rate of Settling.

EFFECT OF POSITION OF SETTLING VESSEL. When a sample of typical stockyards activated sludge is settled in glass cylinders, the following is noted. The particles of activated sludge are finely divided, coming from the aeration tanks. Flocculation takes place immediately. Within a few minutes a marked increase in the size of particles occurs. Five minutes usually elapse before any settling is noted, after which the rate increases and then gradually decreases. A distinct upward as well as downward motion of the sludge particles may be noted throughout the entire cylinder. The particles of sludge moving up are much smaller in size than those moving down, and are either carried down by the large particles or gradually increase in size until large enough to settle. This up and down motion interferes with the free settling of the sludge, and may account for the rate of concentration in shallow tanks being faster than in deep tanks. By inclining a cylinder containing a mixture of sewage and sludge, after flocculation sets in, a uniform circulation of the sludge begins which materially aids in the settling, as the upward motion of the sludge does not interfere with the downward motion.

Tests conducted on Nov. 20, 1917, show the effect of increased inclination, (Table 52, Fig. 20). Seven cylinders were placed in a rack to obtain angles ranging from 90 to 30 deg. with the horizontal. The sludge in the inclined cylinders settled very rapidly during the first 20 minutes. The same degree of concentration was obtained in 20 minutes in the 60 deg. cylinder as was obtained in one hour in the vertical cylinder. The rate of subsidence was slightly greater at 51 than 60 deg. With angles less than 45 deg., the sludge would not slide to the bottom of the cylinder, making measurements of percentage of sludge rather inaccurate. As the rate of subsidence is a function of many factors, tests were made with sludge from the aeration tanks as well as from the re-aeration tanks, on several different days when the state of activation of the sludge was different. The curves for November 20 are typical of activated sludge during cold weather. The curves for July 26 are typical of a well activated sludge from the settling tank after re-aeration for a few hours. The curves for July 23 are typical of a very well activated sludge in summer.

Table 52 indicates that the same concentration can be effected with quiescent settling in 100 cc. graduated glass cylinders in about 20 minutes in a cylinder at 60 deg., as in one hour with the cylinder vertical. This principle was utilized in the continuous

flow settling tank (Tank 8). The available surface area of the tank was 45 sq. ft., divided into three sections each 3 by 5 ft. An equal volume of sewage was introduced into each section through an influent distributor. The wooden baffles were placed at 60 deg.

This tank successfully settled flows (effluent) varying from 950 to 1400 gal. per sq. ft. tank area per 24 hr., while tanks of the Dortmund type, horizontal flow and combined vertical and horizontal flow types could succesfully treat only 500 to 650 gal. per sq. ft. The latter figures are lower than for plants handling domestic sewage. The calculations are based on volume of effluent alone, not effluent plus sludge.

# CHAPTER IX.

## COMPOSITION AND RECOVERY OF ACTIVATED SLUDGE.

COMPOSITION. Typical activated sludge from Packingtown sewage is brown in color and resembles activated sludge produced from domestic sewage. It settles quickly, with a distinct line of demarcation between the clear liquid and the sludge.

Analyses of sludge for the two major periods of operation (Tables 53, 54 and 55) indicate that the moisture content of the re-aerated and re-settled sludge was almost as great as that of the sludge from the primary settling tank. The sludge from the primary settling tank in 1916 was more concentrated than that from the re-settling tank in 1917. In practically all analyses the sludge contained more than 99 per cent water. In 1916 the dry sludge contained less volatile matter than in 1917. The greater amount of screenings, largely of organic nature, removed in 1916 accounts for the lower amount of volatile matter in the sludge.

Organic nitrogen varied from 2.88 to 5.60 per cent of the dry sludge in 1916, averaging 4.17 per cent. In 1917 it varied from 3.04 to 6.40 per cent in the sludge from the primary settling tank, averaging 4.47 per cent. The organic nitrogen in the re-aerated sludge varied from 2.88 to 6.24, averaging 4.43 per cent. The ether soluble content varied over wide limits averaging 6.00 per cent in 1916, and 5.45 in 1917, and after acidification 9.25 per cent in 1916, 6.85 in 1917.

A comparison of the analysis of activated sludge with that of other sludges produced at the Stockyards Testing Station is given in the following table.

**TABLE 56**

COMPARISON OF SLUDGE ANALYSES

Stockyards Testing Station

| Sludge | Sp. Gr. | Percent Moisture | Calculated to Dry Weight, Percent | | | |
|---|---|---|---|---|---|---|
| | | | Nitrogen | Volatile | Fixed | Ether Sol. |
| Activated Sludge | 1.004 | 99.15 | 4.17 | 62.6 | 37.4 | 6.0 |
| Imhoff | 1.02 | 91.5 | 2.72 | 65. | 35. | 6.6 |
| Dortmund Tank D | 1.02 | 91.7 | 2.88 | 76. | 24. | 8.6 |
| Dortmund Tank C | 1.02 | 90.6 | 2.65 | 72. | 28. | 8.1 |
| Screenings | ....... | 80.7 | 2.18 | 95.3 | 4.7 | 5.9 |

# TABLE 53

ACTIVATED SLUDGE. ANALYSES OF SLUDGE

September 22, 1916 to March 23, 1917

| Date | Source Tank | Specific Gravtiy | Moisture | Calculated to Dry Weight | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Fixed Matter | Volatile Matter | Organic Nitrogen | Ether Soluble | | |
| | | | | | | | As Is | Acidified | |
| 1916 | | | | | | | | | |
| Sept. 22 | 6 | 1.009 | 98.7 | 34.0 | 66.0 | 3.52 | 4.20 | 9.24 | Screen not in Oper'n |
| 29 | 6 | 1.005 | 98.9 | 40.8 | 59.2 | 3.82 | 3.18 | 8.00 | Considerable Straw and Hair Present |
| Oct. 6 | 6 | 1.005 | 99.4 | 43.7 | 56.3 | 3.68 | 2.92 | 6.90 | |
| 13 | 6 | 1.004 | 99.1 | 35.3 | 64.7 | 4.00 | 3.73 | 8.08 | |
| 20 | 6 | 1.004 | 98.7 | 33.3 | 66.7 | 3.84 | 7.02 | 9.98 | |
| 27 | 6 | 1.004 | 99.1 | 35.5 | 64.5 | 4.00 | 5.90 | 9.10 | |
| Nov. 3 | 6 | 1.004 | 99.6 | 44.9 | 55.1 | 2.88 | 3.54 | 6.42 | |
| 10 | 6 | 1.004 | 99.3 | 39.0 | 61.0 | 4.16 | 4.80 | 7.76 | |
| 17 | 6 | 1.004 | 99.1 | 33.2 | 66.8 | 3.84 | 7.26 | 9.86 | |
| 24 | 6 | 1.004 | 99.23 | 39.2 | 60.8 | 4.16 | 7.08 | 10.52 | $P_2O_5$—2.67 |
| Dec. 1 | 6 | 1.004 | 99.11 | 31.4 | 68.6 | 4.64 | 4.82 | 8.30 | $K_2O$—1.55 |
| 9 | 6 | 1.004 | 99.37 | 38.3 | 61.7 | 4.80 | 4.28 | 5.84 | |
| 15 | 6 | 1.004 | 99.05 | 30.0 | 70.0 | 5.12 | 7.50 | 12.12 | |
| 22 | 6 | 1.004 | 99.55 | 38.1 | 61.9 | 3.68 | 3.86 | 9.26 | |
| 29 | 6 | 1.004 | 99.14 | 32.3 | 67.8 | 5.28 | 13.90 | 14.74 | $P_2O_5$—2.78 |
| 1917 | | | | | | | | | $K_2O$—1.21 |
| Jan. 5 | 6 | 1.004 | 99.07 | 28.1 | 71.9 | 5.44 | 10.86 | 12.50 | |
| 19 | 6 | 1.004 | 99.39 | 32.9 | 67.1 | 5.60 | 7.90 | 11.18 | |
| 26 | 6 | 1.002 | 99.67 | 45.3 | 54.7 | 3.68 | 3.24 | 9.12 | |
| Feb. 2 | 6 | 1.004 | 99.47 | 34.4 | 65.6 | 4.48 | 7.14 | 12.12 | |
| 9 | 6 | 1.004 | 99.32 | 29.7 | 70.3 | 5.44 | 6.46 | 13.38 | |
| 16 | 6 | 1.004 | 99.42 | 30.6 | 69.4 | 4.16 | 7.46 | 15.54 | |
| 23 | 6 | 1.004 | 99.14 | 28.1 | 71.9 | 4.96 | 9.50 | 12.26 | |
| Mar. 2 | 6 | 1.004 | 99.14 | 26.6 | 73.4 | 5.12 | 9.64 | 13.94 | |
| 9 | 4 | 1.004 | 99.29 | 32.9 | 67.1 | 4.16 | 8.86 | 11.66 | |
| 16 | 4 | 1.004 | 99.33 | 36.5 | 63.5 | 3.36 | 4.54 | 8.06 | |
| 23 | 4 | 1.004 | 99.08 | 38.4 | 61.6 | 3.04 | 4.08 | 6.64 | |
| Average | Sept. 15, '16 to Mar. 26, 1917 | 1.004 | 99.22 | 35.1 | 64.9 | 4.27 | 6.30 | 10.10 | |
| Average | July 1 to Sept. 15, '16 | 1.003 | 99.0 | 43.2 | 56.8 | 3.96 | 5.33 | 7.25 | |
| Average | July 1, '16 to Mar. 26, 1917 | 1.004 | 99.15 | 37.4 | 62.6 | 4.17 | 6.00 | 9.25 | |

# TABLE 54

ACTIVATED SLUDGE. ANALYSES OF SLUDGE.

March 31 to October 8, 1917

| Date 1917 | Source Tank | Specific Gravity | Moisture | Calculated to Dry Weight | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Fixed Matter | Volatile Matter | Organic Nitrogen | Ether Soluble | | |
| | | | | | | | As Is | Acidified | |
| Mar. 31 | D | 1.004 | 99.44 | 34.3 | 65.7 | 3.68 | 3.88 | 8.08 | |
| April 6 | D | 1.00 | 99.45 | 42.4 | 57.6 | 3.36 | 5.54 | 8.02 | |
| 14 | D | 1.00 | 99.62 | 22.3 | 77.7 | 6.24 | 8.06 | 8.42 | |
| 20 | D | 1.00 | 99.70 | 22.6 | 77.4 | 6.24 | 8.14 | 8.96 | |
| 27 | D | 1.00 | 99.68 | 19.1 | 80.9 | 6.40 | 10.16 | 11.72 | |
| May 4 | D | 1.004 | 99.66 | 29.5 | 70.5 | 5.12 | 9.82 | 12.26 | |
| 11 | D | 1.00 | 99.64 | 20.6 | 79.4 | 3.36 | 5.22 | 5.46 | |
| 18 | D | 1.00 | 99.69 | 51.4 | 48.6 | 3.04 | 4.46 | 6.30 | |
| 25 | D | 1.00 | 99.65 | 47.0 | 53.0 | 3.04 | 3.70 | 6.00 | |
| June 5 | D | 1.00 | 99.67 | 30.8 | 69.2 | 3.52 | 6.34 | 9.32 | |
| 11 | D | 1.00 | 99.67 | 28.9 | 71.1 | 4.32 | *2.86 | *4.10 | *Petroleum Ether Used |
| 18 | D | 1.00 | 99.64 | 31.4 | 68.6 | 5.44 | *3.70 | *4.74 | |
| 25 | D | 1.004 | 99.61 | 29.5 | 70.5 | 5.60 | 5.46 | 6.14 | |
| July 2 | D | 1.004 | 99.50 | 26.0 | 74.0 | 4.32 | 5.90 | 6.86 | |
| 9 | D | ........ | 99.35 | 28.7 | 71.3 | 4.64 | 5.56 | 5.82 | |
| 23 | D | 1.00 | 99.60 | 38.1 | 61.9 | 3.52 | ........ | 5.04 | |
| 31 | D | 1.01 | 99.60 | 28.2 | 71.8 | 4.80 | 7.78 | 8.24 | |
| Aug. 6 | D | 1.00 | 99.68 | 29.4 | 70.6 | 5.12 | 5.30 | 6.36 | |
| 13 | D | 1.01 | 99.64 | 25.4 | 74.6 | ........ | 4.42 | 4.72 | |
| 27 | D | 1.01 | 99.61 | 34.0 | 66.0 | 4.00 | 4.74 | 5.14 | |
| Sept. 10 | D | 1.007 | 99.53 | 27.4 | 72.6 | 4.48 | 5.08 | 6.66 | |
| 17 | D | 1.012 | 99.31 | 30.0 | 70.0 | 4.16 | 2.94 | 4.46 | |
| 26 | D | 1.01 | 99.35 | 24.7 | 75.3 | 4.16 | 3.68 | 5.50 | |
| Oct. 1 | D | ........ | 99.39 | 28.4 | 71.6 | 4.16 | 3.86 | 5.54 | |
| 8 | D | 1.013 | 99.47 | 27.9 | 72.1 | 4.64 | 4.40 | 5.26 | |
| Average | ........ | 1.004 | 99.57 | 30.3 | 69.7 | 4.47 | 5.46 | 6.76 | |

# TABLE 55

ACTIVATED SLUDGE. ANALYSES OF RE-AERATED SLUDGE

March 31 to October 8, 1917

| Date 1917 | Source Tank | Specific Gravity | Moisture | Calculated to Dry Weight | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Fixed Matter | Volatile Matter | Organic Nitrogen | Ether Soluble | | |
| | | | | | | | As Is | Acidified | |
| Mar. 31 | 6 | 1.004 | 99.32 | 32.0 | 68.0 | 3.36 | 5.90 | 8.42 | |
| April 6 | 6 | 1.00 | 99.40 | 38.8 | 61.2 | 3.84 | 5.50 | 8.36 | |
| 14 | 6 | 1.004 | 99.45 | 25.5 | 74.5 | 5.76 | 7.16 | 8.54 | |
| 20 | 6 | 1.004 | 99.50 | 22.2 | 77.8 | 5.02 | 8.28 | 9.78 | |
| 27 | 6 | 1.004 | 99.54 | 28.5 | 71.5 | 5.28 | 9.92 | 11.64 | |
| May 4 | 6 | 1.004 | 99.47 | 24.8 | 75.2 | 6.24 | 9.14 | 12.28 | |
| 11 | 6 | 1.004 | 99.60 | 44.8 | 55.2 | 3.20 | 4.78 | 7.04 | |
| 18 | 6 | 1.00 | 99.62 | ...... | ...... | ...... | ...... | ...... | |
| 25 | 6 | 1.00 | 99.75 | 46.7 | 53.3 | 2.88 | 2.78 | 4.16 | |
| June 5 | 6 | 1.00 | 99.58 | 30.5 | 69.5 | 4.80 | 6.14 | 8.14 | |
| 11 | 6 | 1.004 | 99.53 | 24.7 | 75.3 | 4.64 | *2.64 | *3.48 | *Petroleum Ether Used |
| 18 | 6 | 1.00 | 99.46 | 32.3 | 67.7 | 4.64 | 3.16 | 3.82 | |
| 25 | 6 | 1.004 | 99.37 | 27.8 | 72.2 | 5.60 | 6.18 | 6.40 | |
| July 2 | 6 | 1.004 | 99.22 | 32.5 | 67.5 | 4.48 | 5.70 | 6.66 | |
| 9 | 6 | ...... | 99.12 | 31.8 | 68.2 | 3.84 | 6.54 | 7.26 | |
| 23 | 6 | 1.006 | 99.60 | 34.7 | 65.3 | 4.00 | 4.98 | 6.68 | |
| 31 | 6 | 1.01 | 99.45 | 28.1 | 71.9 | 4.80 | 7.48 | 9.52 | |
| Aug. 6 | 6 | 1.01 | 99.69 | 27.4 | 72.6 | 4.64 | 4.70 | 5.94 | |
| 13 | 6 | 1.01 | 99.53 | 28.5 | 71.5 | ...... | 4.80 | 5.52 | |
| 27 | 6 | 1.01 | 99.27 | 35.2 | 64.8 | 4.64 | 4.32 | 4.76 | |
| Sept. 10 | 6 | 1.007 | 99.40 | 28.8 | 71.2 | 4.16 | 5.16 | 6.50 | |
| 17 | 6 | 1.012 | 98.90 | 30.8 | 69.2 | 3.68 | 4.18 | 4.38 | |
| 26 | 6 | 1.007 | 98.94 | 31.4 | 68.6 | 4.32 | 3.68 | 6.54 | |
| Oct. 1 | 6 | 1.01 | 99.14 | 32.0 | 68.0 | 4.16 | 3.54 | 5.55 | |
| 8 | 6 | 1.01 | 99.19 | 28.9 | 71.1 | 4.00 | 3.76 | 5.32 | |
| Average | ...... | 1.005 | 99.40 | 31.2 | 68.8 | 4.43 | 5.43 | 6.95 | |

Activated sludge differs from the other sludges formed from Packingtown sewage, being more liquid, higher in nitrogen, and lower in fat content than Imhoff or Dortmund tank sludge.

RECOVERY OF SUSPENDED SOLIDS AS SLUDGE. Careful records were kept and analyses made of the sludge wasted daily. The weight of dry sludge was calculated. After Sept. 17, 1916, a comparison was made of the weight of dry sludge and the weight of dry suspended solids removed, in order to determine the extent of liquefaction and gasification of sludge.

In calculating the equivalent dry weight of sludge from the moisture content as determined, due allowance was made for the solids in solution. Analyses were made of several samples of supernatant liquid from settled sludge. An average of 2,000 p. p. m. or 0.2 percent solids in solution was found. The error resulting from this source is considerable (Table 57) when the moisture content of the sludge exceeds 99 percent, while with a moisture content as low as 90 percent, the error is only 2 percent.

**TABLE 57**

ERROR IN DETERMINATION OF PERCENT MOISTURE

Based on Solids in Solution Averaging 0.2 Percent

| Moisture Percent | Percent Error |
|---|---|
| 99.8 | 100 |
| 99.7 | 67 |
| 99.6 | 50 |
| 99.5 | 40 |
| 99.4 | 33 |
| 99.1 | 22 |
| 99.0 | 20 |
| 98.0 | 10 |
| 96.0 | 5 |
| 90.0 | 2 |

The average weight of dry sludge produced per million gallons during the first period, 1916-17, is given in Table 58. As no sludge was wasted while accumulating activated sludge, the first month of operation showed very low production of excess sludge. After the necessary sludge had been accumulated, comparison was made with the suspended solids removed (Table 59). During the entire period the average amount of sludge removed from the settling tanks was 46,500 gal., equivalent to 2,420 lb. dry, per million gallons of sewage. For the runs during which the removal of sludge was compared with the removal of suspended solids, 2,680 lb. of dry sludge were discharged and 2,820 lb. produced from the suspended solids, per million gallons of sewage, corresponding

to a recovery of 95 percent, or a digestion of only 5 percent. The total suspended solids in the summary are true averages, with day, night, Sunday and holiday samples weighted according to their respective flows.

**TABLE 58**

REMOVAL OF SLUDGE

July 1, 1916 to March 26, 1917

| Period | Sewage Treated Gallons | Sludge | | | |
|---|---|---|---|---|---|
| | | Gallons Disposed | Equiv. Lbs. Dry | Per Mil. Gal. Sewage | |
| | | | | Dry Pounds | Gallons |
| 1916 | | | | | |
| July 1 to 31 | 1,556,700 | 13,775 | 1,723 | 1,100 | 8,900 |
| Aug. 1 to 31 | 2,003,300 | 57,290 | 3,998 | 2,000 | 28,600 |
| Sept. 1 to 16 | 1,100,500 | 44,070 | 2,532 | 2,300 | 40,000 |
| Sept. 17 to Oct. 14 | 1,889,650 | 72,970 | 4,207 | 2,220 | 38,600 |
| Oct. 15 to 22 | 550,100 | 24,420 | 1,386 | 2,520 | 44,300 |
| Oct. 23 to Nov. 23 | 2,720,900 | 193,420 | 6,913 | 2,540 | 71,000 |
| Nov. 24 to Dec. 7 | 942,050 | 47,420 | 4,238 | 4,500 | 50,400 |
| Dec. 8 to 15 | 566,700 | 45,610 | 2,010 | 3,540 | 80,400 |
| Dec. 16 to Jan. 7, 1917 | 1,672,250 | 117,940 | 6,557 | 3,920 | 70,500 |
| Jan. 8 to Feb. 4 | 1,335,400 | 60,610 | 2,333 | 1,750 | 45,300 |
| Feb. 5 to Mar. 5 | 2,053,600 | 75,700 | 3,889 | 1,900 | 37,000 |
| Mar. 5 to 26 | 799,000 | 48,630 | 1,920 | 2,400 | 60,700 |
| Total | 17,190,150 | 801,855 | 41,706 | | |
| Average | | | | 2,420 | 46,500 |

For the second major period, Mar. 27 to Nov. 14, 1917, only 1924 lb. of dry sludge was removed per million gallons of sewage (Table 60), less than during the preceding period, when 2,420 pounds were removed. This is explained by the lower removal of suspended solids in 1917, amounting to 273 p. p. m. as compared with 333 p. p. m. in 1916. The 1917 period did not include the winter months, when suspended solids increased markedly in Packingtown sewage due to the increased killing.

Compared with this 1924 lb. of dry sludge, 2,280 lb. of dry suspended solids were removed (Table 61), per million gallons, indicating a recovery of 84 percent. The increased digestion during 1917 may be due to re-aeration of sludge, or to more active hydrolysis of solids in warm weather during which the 1917 results were obtained.

The digestion of solids appears surprisingly low in view of the intense bacterial activity in the activated sludge process. A high percentage recovery of sludge probably results from consistent daily removal of increments of sludge. The digestion would be considerably greater than 5 to 15 percent, if sludge were allowed to accumulate in the aeration tanks above the 20 to 40 percent considered necessary for the proper operation of the process.

## TABLE 59

REMOVAL OF SLUDGE AND SUSPENDED MATTER

September 17, 1916 to March 26, 1917

| Period | Sewage Treated Gallons | Total Suspended Matter | | | | | Dry Sludge Removed | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Crude (Screened) P. P. M. | Combined Effluent P. P. M. | Reduction | | | Total Pounds | Pounds per Million Gal. Sewage | |
| | | | | P. P. M. | Total Pounds | Pounds per Million Gals. Sewage | | | |
| 1916 | | | | | | | | | |
| Sept. 17 to Oct. 15 | 1,889,650 | 410 | 46 | 364 | 5,730 | 3,030 | 4,207 | 2,220 | Screen Not Working |
| Oct. 15 to Oct. 23 | 550,100 | 340 | 38 | 302 | 1,385 | 2,520 | 1,386 | 2,520 | |
| Oct. 23 to Nov. 24 | 2,720,900 | 437 | 32 | 405 | 9,170 | 3,370 | 6,913 | 2,540 | |
| Nov. 24 to Dec. 8 | 942,050 | 441 | 38 | 403 | 3,160 | 3,360 | 4,238 | 4,500 | |
| Dec. 8 to Dec. 16 | 566,700 | 420 | 55 | 365 | 1,720 | 3,040 | 2,010 | 3,540 | |
| Dec. 16, '16 to Jan. 8, '17 | 1,672,250 | 375 | 64 | 311 | 4,330 | 2,590 | 6,557 | 3,920 | |
| 1917 | | | | | | | | | |
| Jan. 8 to Feb. 5 | 1,335,400 | 326 | 56 | 270 | 3,000 | 2,250 | 2,333 | 1,750 | |
| Feb. 5 to Mar. 6 | 2,053,600 | 330 | 30 | 300 | 5,020 | 2,500 | 3,889 | 1,900 | Screen Not Working Feb. 6 to 16 |
| Mar. 6 to Mar. 26 | 799,000 | 295 | 22 | 273 | 1,820 | 2,270 | 1,920 | 2,400 | |
| Total | 12,529,650 | ........ | ........ | ........ | 35,335 | ........ | 33,453 | ........ | |
| Average | ........ | ........ | ........ | 333 | ........ | 2,820 | ........ | 2,680 | |

NOTE:—Screen Working Unless Otherwise Noted.

**TABLE 60**

REMOVAL OF SLUDGE

March 27 to November 14, 1917

| Period | Sewage Treated Gallons | Sludge | | | |
|---|---|---|---|---|---|
| | | Gallons Disposed | Equiv. Lbs. Dry | Per Mil. Gal. Sewage | |
| | | | | Dry Pounds | Gallons |
| 1917 | | | | | |
| Mar. 27 to April 22 | 1,734,600 | 136,350 | 5,911 | 3,420 | 78,700 |
| April 23 to May 30 | 1,775,100 | 152,100 | 4,615 | 2,600 | 85,700 |
| May 31 to July 1 | 2,122,000 | 123,390 | 4,979 | 2,340 | 58,100 |
| July 2 to July 22 | 1,405,750 | 62,560 | 3,563 | 2,540 | 44,500 |
| July 23 to Aug. 8 | 1,086,300 | 35,350 | 1,057 | 975 | 32,550 |
| Aug. 9 to Aug. 21 | 910,650 | 10,690 | 734 | 806 | 11,750 |
| Aug. 22 to Sept. 23 | 2,294,250 | 59,640 | 3,562 | 1,550 | 26,000 |
| Sept. 24 to Oct. 12 | 1,347,950 | 33,750 | 2,227 | 1,650 | 25,050 |
| Oct. 13 to Oct. 21 | 696,550 | 18,270 | 1,525 | 2,190 | 26,250 |
| Oct. 22 to Nov. 14 | 1,676,500 | 29,460 | 1,962 | 1,170 | 18,950 |
| Total | 15,049,650 | 661,560 | 30,135 | | |
| Average | | | | 1,924 | 40,750 |

In connection with the digestion of the sludge, it is noteworthy that activated sludge produced at most testing stations in the U. S., is much lower in fat content than any other types of sludge. This indicates that the hydrolysis of fatty substances, probably by splitting up of fatty acids, is more vigorous under the aerobic conditions present in the activated sludge process than in the anaerobic environment in the Imhoff or Dortmund tank.

NITROGEN RECOVERY. The nitrogen balance for the two major periods of operation may be calculated if the assumptions are made that (1) the amount of sludge retained in the aerating and settling tanks remains fairly constant after the amount necessary for proper operation has been accumulated, and (2) the influent contains a negligible quantity of nitrite and nitrate nitrogen. The first assumption is true if sludge is removed from the system daily in proportion to the increments of solid matter entering with the influent, and if in the schedule of operation this daily proportionate removal of sludge is maintained. Over a long period of operation any discrepancies between the input and outgo will tend to disappear.

The total nitrogen entering the system will then comprise the weight of nitrogen in the influent in combination as ammonia and organic nitrogen (the nitrites and nitrates being ignored) and the

## TABLE 61

REMOVAL OF SLUDGE AND SUSPENDED MATTER

March 27 to November 14, 1917

| Period 1917 | Sewage Treated Gallons | Total Suspended Matter | | | | | Dry Sludge Removed | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Crude (Screened) P. P. M. | Combined Effluent P. P. M. | Reduction | | | Total Pounds | Pounds per Million Gal. Sewage | |
| | | | | P. P. M. | Total Pounds | Pounds per Million Gals. Sewage | | | |
| Mar. 27 to April 22 | 1,734,600 | 373 | 25 | 248 | 3,580 | 2,060 | 5,911 | 3,420 | |
| April 23 to May 30 | 1,775,100 | 331 | 31 | 300 | 4,435 | 2,490 | 4,615 | 2,600 | |
| May 31 to July 1 | 2,122,000 | 271 | 18 | 253 | 4,475 | 2,110 | 4,979 | 2,340 | |
| July 2 to July 22 | 1,405,750 | 284 | 24 | 260 | 3,040 | 2,160 | 3,563 | 2,540 | |
| July 23 to Aug. 8 | 1,086,300 | 250 | 33 | 217 | 1,960 | 1,800 | 1,057 | 975 | |
| Aug. 9 to Aug. 21 | 910,650 | 264 | 20 | 244 | 1,850 | 2,030 | 734 | 806 | |
| Aug. 22 to Sept. 23 | 2,294,250 | 322 | 25 | 297 | 5,675 | 2,470 | 3,562 | 1,550 | |
| Sept. 24 to Oct. 12 | 1,347,950 | 322 | 16 | 306 | 3,440 | 2,550 | 2,227 | 1,650 | |
| Oct. 13 to Oct. 21 | 696,550 | 359 | 18 | 341 | 1,980 | 2,840 | 1,525 | 2,190 | |
| Oct. 22 to Nov. 14 | 1,676,500 | 305 | 28 | 277 | 3,865 | 2,310 | 1,962 | 1,170 | |
| Total | 15,049,650 | ....... | .... | ....... | 34,300 | ........... | 30,135 | ........... | |
| Average | .................. | ....... | .... | 273 | ........... | 2,280 | ........... | 1,924 | |

# TABLE 62

ACTIVATED SLUDGE. NITROGEN BALANCE SHEET

First Period Aug. 1, 1916 to March 26, 1917

| No. of Run | Length of Run 1916-1917 | Influent Pounds per M. G. | | | Effluent Pounds per M. G. | | | | Sludge | | | Total N Recovered Effluent Plus Sludge Lbs. per M. G. | Loss Influent--(Sludge Plus Effluent) Lbs. per M. G. | Percent Loss Total N. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Amm. N | T. O. N. | Total | Amm. N | T. O. N. | Nitrite Plus Nitrate N | Total | Dry lbs. per M. G. | Percent N | Lb. N per M. G. | | | |
| 4-5 | Aug. 1 to 31, 1916 | 125 | 300 | 425 | 73 | 60 | 71 | 204 | 2,000 | 4.17 | 83 | 287 | 138 | 31 |
| 6 | Sept. 1 to 16 | 117 | 342 | 459 | 43 | 43 | 49 | 135 | 2,300 | 4.17 | 96 | 231 | 228 | 50 |
| 7 | Sept. 17 to Oct. 14 | 150 | 375 | 525 | 93 | 70 | 26 | 189 | 2,200 | 3.75 | 83 | 272 | 253 | 48 |
| 8 | Oct. 15 to 22 | 117 | 350 | 467 | 123 | 71 | 23 | 217 | 2,520 | 3.84 | 97 | 314 | 153 | 33 |
| 9 | Oct. 23 to Nov. 23 | 142 | 492 | 634 | 237 | 88 | 4 | 329 | 2,540 | 3.72 | 94 | 423 | 211 | 33 |
| 10 | Nov. 24 to Dec. 7 | 142 | 558 | 700 | 240 | 117 | 2 | 359 | 4,500 | 4.40 | 198 | 557 | 143 | 20 |
| 11 | Dec. 8 to 15 | 125 | 527 | 652 | 258 | 108 | 2 | 368 | 3,540 | 4.96 | 176 | 544 | 108 | 16 |
| 12 | Dec. 16 to Jan. 7, 1917 | 125 | 535 | 660 | 208 | 167 | 2 | 377 | 3,920 | 4.80 | 188 | 565 | 95 | 14 |
| 13 | Jan. 8 to Feb. 4 | 108 | 442 | 550 | 200 | 108 | 1 | 309 | 1,750 | 4.58 | 71 | 380 | 170 | 31 |
| 14 | Feb. 5 to Mar. 5 | 92 | 417 | 509 | 175 | 100 | 1 | 276 | 1,900 | 4.92 | 93 | 369 | 140 | 27 |
| 15 | Mar. 6 to 26 | 108 | 333 | 441 | 142 | 100 | 2 | 244 | 2,400 | 3.52 | 84 | 328 | 113 | 26 |
| Average Runs 4 to 8 inc. | | 127 | 342 | 469 | 83 | 61 | 42 | 186 | 2,260 | 3.98 | 90 | 276 | 193 | 41 |
| Average Runs 9 to 15 inc. | | 120 | 472 | 592 | 209 | 113 | 2 | 324 | 2,940 | 4.41 | 130 | 454 | 138 | 23 |
| Average, total | | 123 | 425 | 548 | 163 | 94 | 17 | 274 | 2,690 | 4.26 | 115 | 389 | 159 | 29 |

NOTE:—T. O. N. is Abbreviation for Total Organic Nitrogen.

## TABLE 63

ACTIVATED SLUDGE. NITROGEN BALANCE SHEET

Second Period March 27 to November 14, 1917

| No. of Run | Length of Run 1917 | Influent Pounds per M. G. | | | Effluent Pounds per M. G. | | | | Sludge | | | Total N Recovered Effluent Plus Sludge Lbs. per M. G. | Loss Influent—(Sludge Plus Effluent) Lbs. per M. G. | Percent Loss Total N. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Amm. N | T. O. N. | Total | Amm. N | T. O. N. | Nitrite Plus Nitrate N | Total | Dry lbs. per M. G. | Percent N | Lb. N per M. G. | | | |
| 16 | Mar. 27 to April 22 | 92 | 308 | 400 | 150 | 92 | 5 | 247 | 3,420 | 4.49 | 154 | 401 | 0 | 0 |
| 17 | April 23 to May 30 | 108 | 342 | 450 | 142 | 75 | 8 | 225 | 2,600 | 4.40 | 114 | 339 | 111 | 25 |
| 18 | May 31 to July 1 | 108 | 308 | 416 | 92 | 56 | 18 | 166 | 2,340 | 4.92 | 115 | 281 | 135 | 32 |
| 19 | July 2 to July 22 | 117 | 258 | 375 | 100 | 50 | 14 | 164 | 2,540 | 4.10 | 104 | 268 | 107 | 28 |
| 20 | July 23 to Aug. 8 | 108 | 258 | 366 | 42 | 67 | 33 | 142 | 975 | 4.72 | 46 | 188 | 178 | 48 |
| 21 | Aug. 9 to Aug. 21 | 125 | 208 | 333 | 42 | 33 | 41 | 116 | 806 | 4.64 | 37 | 153 | 180 | 54 |
| 22 | Aug. 22 to Sept. 23 | 117 | 208 | 325 | 42 | 25 | 46 | 113 | 1,550 | 4.12 | 64 | 177 | 148 | 45 |
| 23 | Sept. 24 to Oct. 12 | 100 | 283 | 383 | 42 | 25 | 51 | 118 | 1,650 | 4.12 | 68 | 186 | 197 | 51 |
| 24 | Oct. 13 to Oct. 21 | 92 | 267 | 359 | 75 | 42 | 21 | 138 | 2,190 | 4.43 | 97 | 235 | 124 | 34 |
| 25 | Oct. 22 to Nov. 14 | 92 | 300 | 392 | 108 | 50 | 13 | 171 | 1,170 | 4.43 | 52 | 223 | 169 | 43 |
| Average | | 106 | 274 | 380 | 84 | 52 | 25 | 161 | 1,920 | 4.44 | 85 | 246 | 134 | 35 |

nitrogen leaving the system will include that in combination as ammonia, organic nitrogen, nitrites and nitrates plus the total weight of nitrogen in the sludge removed. The difference between these two summations will represent the nitrogen lost in gaseous form as free nitrogen or nitrous oxide.

These relations are indicated, in Tables 62 and 63, calculated to pounds per million gallons. Prior to the accumulation of an average quantity of sludge on August 1, 1916, runs are omitted. In the second period sufficient sludge was present in the tanks at the beginning of operation, so that no allowance was made for accumulation of sludge.

In the first period Runs 4 to 8 inclusive are considered as under summer conditions, Runs 9 to 15 as under winter conditions. A decided difference in results is indicated. In summer a relatively large proportion of nitrogen is lost in gaseous form; in winter the greatest loss occurs in soluble form, as ammonia nitrogen. The apportionment of loss is more apparent from Table 64.

**TABLE 64**

RELATION OF NITROGEN CHANGES

| Aug. 1, 1916 to Mar. 26, 1917 | | Total Input Influent | Changed to | | | | |
|---|---|---|---|---|---|---|---|
| | | | Ammonia Nitrogen | Organic Nitrogen | Nitrite Plus Nitrate Nitrogen | Nitrogen Gas or Nitrous Oxide | Removed as Sludge |
| Summer | Pounds per M. G. | 469 | 83 | 61 | 42 | 193 | 90 |
| | Percent of Total | 100 | 18 | 13 | 9 | 41 | 19 |
| Winter | Pounds per M. G. | 592 | 209 | 113 | 2 | 138 | 130 |
| | Percent of Total | 100 | 36 | 19 | 0 | 23 | 22 |

These results indicate that more nitrogen in insoluble form is recovered in cold weather correlated with a correspondingly lower loss in gaseous nitrogen. The large loss of nitrogen in gaseous form in warm weather is mainly due to reduction of nitrates to nitrites by denitrifying bacteria and subsequent reaction of nitrites with ammonia or amino-acid nitrogen to form free nitrogen. In winter the temperature appears to be too low for rapid formation of nitrates, although ammonification proceeds rapidly.

The recovery of nitrogen from sewage is the feature of the activated sludge process that appeals most strongly to the laymen. These figures indicate that only 19 to 22 per cent of the nitrogen originally present in stockyards sewage is recovered in the sludge,

the rest escaping in soluble form with the effluent or into the air as an insoluble gas. The loss of total nitrogen as gas is comparable with that occurring in treatment in contact beds, given as from 18 to 46 per cent by Clark on the basis of many years' experiments at Lawrence with domestic sewage. A much lower loss occurs during treatment in sand beds or in sprinkling filters.

Tables 63 and 65 show the nitrogen changes occuring during the second period of operation, from March 27 to Nov. 14, 1917. This period as a whole represents summer conditions, and indicates that the loss of gaseous nitrogen is probably considerably less when sludge is re-aerated than when it is returned directly from the primary settling tank.

**TABLE 65**

RELATION OF NITROGEN CHANGES

Re-aeration and Re-settling

| March 27 to Nov. 14, 1917 | Total Input Influent | Changed to | | | | |
|---|---|---|---|---|---|---|
| | | Ammonia Nitrogen | Organic Nitrogen | Nitrite and Nitrate Nitrogen | Nitrogen Gas or Nitrous Oxide | Recovered as Sludge |
| Pounds per M. G. | 380 | 84 | 52 | 25 | 143 | 85 |
| Percent of Total | 100 | 22 | 14 | 7 | 35 | 22 |

# CHAPTER X.

## DRYING AND FILTER-PRESSING ACTIVATED SLUDGE.

The activated sludge process produces an enormous volume of very liquid sludge, which must be handled while comparatively fresh, as the sludge becomes septic in a very short time. The various methods suggested for treatment are as follows: Concentration, lagooning, air drying on sand beds, acid concentration, yeast fermentation (developed at Dublin), filter pressing and heat drying. At the Stockyards testing station experiments were conducted on air drying on sand beds, lagooning, concentration (previously described), and filter pressing.

SAND BEDS. Normal activated sludge will not dry as quickly as Imhoff sludge. When applied to sand beds, much of the water passes through the underdrains while filling and for a short time thereafter. The sludge soon settles to the bottom, forming a mat on the surface of the sand which materially decreases the amount of water passing through into the underdrains. An application 24 in. deep was reduced only 4 in. after remaining on the bed over night. About 14 or 15 in. of clear liquid was siphoned off the surface of the sludge, which then dried very slowly. The sludge in drying developed a large number of small cracks.

The most promising results were obtained with sludge applied on Sept. 12, and removed on Sept. 19, 1916. In this test 24 in. of sludge of 99.3 per cent moisture was applied, which was reduced to 76.1 per cent in 7 days, during which period there was a rainfall of 0.03 inch.

LAGOONING. Lagooning of the sludge was tried, and found to be unsuccessful. The sludge settled to the bottom and water remained on top. Practically the only concentration effected was due to evaporation and very slow percolation into the soil. Considerable odor developed.

CONCENTRATION. The concentration effected by gravity is described in Chapter VIII. The addition of acid to activated sludge, followed by quiescent settling, made but slight improvement. The most marked effect of the addition, measured by reduction in per cent of moisture, is on filter pressing.

FILTER PRESSING. Experiments on filter pressing were started on June 21, 1917, and continued to Nov. 16, 1917. During this period, 52 tests were made with a small experimental filter press furnished and installed by Mr. W. Buckley of the Simplex Ejector Company of Chicago.

FILTER PRESS. The press was the one used in the earlier experiments at Milwaukee (See Third Report, Milwaukee Sewerage Commission). The apparatus included a 3 x 3½ in. Gardner air compressor operated by a 2 horsepower motor, an air receiver 3 ft. diameter by 6 ft. high, an ejector 3½ ft. in diameter by 4½ ft. high, and a filter press. The press was of the center feed type, the plates being square with a channel 2½ in. diameter at the center. The net filtering area was 225 sq. in. The plates were corrugated, with ridges ¼ in. center to center, and channels 3/16 in. deep. The clear liquid forced through the filter cloth flowed between the ridges to a transverse groove at the bottom of the plate and then through a hole in the lower corners of each plate, provided with a cock. The corrugations were covered with perforated steel strainers which supported the filter cloths. The press comprised 12 corrugated and 2 solid end plates, the latter smooth, without corrugations or strainers. Hence during the tests only 11 chambers were effective.

OPERATION OF PRESS. In operating the press, the ejector was filled with sludge either by gravity or by pumping. The sludge was then forced into the press by air pressure which was gradually increased in the air receiver. Operation was generally started with an initial pressure of about 15 lbs. per sq. in. and gradually increased to a maximum of 140 to 145 lbs. per sq. in. The maximum pressure was generally built up in about 2 hours, and maintained to the end of the test. The best operating results were obtained by the following schedule of air pressure in lbs. per sq. inch: At start 15, at ½ hr. 60, at 1 hr. 100, at 2 hrs. 140.

The actual time consumed in pressing varied from 2 to 5 hours. Water pockets occasionally formed in the ejector, after the pressing had progressed from 2 to 3 hours, because of the sludge settling in the ejector during the time consumed in pressing. When a water pocket was found by inspection (at frequent intervals) of the sludge going to the press, the feed valve was shut down for from 3 to 5 minutes, while the clear liquid was removed from the ejector. This trouble can be avoided in a large installation if an ejector is refilled several times during one pressing. The average

time required to fill the ejector was 5 minutes. The time required to dump the sludge from the press was about 10 minutes. Samples of the sludge as delivered to the ejector, sludge from the ejector at end of test (this was more concentrated because water was often removed from ejector during test), filtrate, and press cake were taken for moisture determinations. The weight of press cake was recorded, the total volume of filtrate, and the rate of filtration, determined by noting the time required to collect successive volumes of 25 gallons of filtrate.

Twenty tests were made with the press as described, but during continuous runs the press was steamed, with the aid of a portable vertical steam boiler. The following conditions were studied during these tests:

1. The efficiency of cotton and linen filter cloths.
2. The effect of sludges of different moisture content.
3. The effect of preliminary acid treatment of sludge.
4. The effect of septic sludge.
5. The effect of continuous runs on the press without removing or washing filter cloths.

The thickness of the press cake during these 20 tests was ⅞ inch. The plates were then changed by Mr. Buckley, by adding 7 ribs on each side, radiating from the center. These ribs practically formed a sectional plate, dividing the cake into 8 equal parts, decreasing the net filtering area, thereby increasing the ratio of drainage area to filtering area. The results obtained with the ribbed plate showed a remarkable improvement over the earlier results obtained with the plain plate. The cake was considerably harder along the ribs than at any other part, except along the outer edge of the plate.

Experiments were then conducted on increased thicknesses of cake, using wood and leather inserts between the plates. Tests were made with cake varying from ⅞ to 1-9/16 inch thick. Tests were also made to determine the relationship between pressings of different time periods and resulting moisture content of the cake, so as to determine the most economical thickness of cake. The effect of adding sulphuric acid, waste sulphuric acid from the dye industry, and nitre cake, was also studied.

The sludge used for the experiments was generally taken direct from the settling tank, settled for 4 to 6 hours, and used as re-

quired. Occasionally it was aerated for about a day before pressing. The degree of concentration of the sludge obtainable in a definite time interval, as well as its behavior towards filter pressing, depends upon the temperature, physical characteristics, and state of activation. In warm weather a typical activated sludge becomes septic in a comparatively short time.

During the first 40 tests, the press was operated by Mr. W. Buckley and later by one of the attendants at the plant. The description and discussion of the results are divided into two parts, Part I comprising tests made before remodeling the plates, and Part II, tests made after remodeling the plates.

## PART I.

Individual Tests, 1 to 20 Inclusive.

Complete data on all 52 tests are given in Tables 66 to 83, inclusive. In recording the various per cent moistures, no correction was made for the total solids in solution, which averaged about 0.2 per cent. The filtrate samples in general were fairly clear but at times contained a small amount of suspended matter, due to tearing of the filter cloths, thus allowing sludge to pass through. In calculating the time of pressing, corrections were made for any interruption such as a water pocket, time of filling the ejector and dumping the press cake.

PRELIMINARY TESTS. The first test on the filter press was made on June 21, 1917, using 6 new cotton duck cloths, and 6 old linen cloths from the Milwaukee experiments. The sludge before pressing contained 99.17 per cent moisture. The net time of pressing was 4 hr. The cake was very wet. The filtrate from the new cotton cloths was cleaner than that from the old linen cloths. In the second test, the 6 linen cloths were replaced with new cotton cloths. With a somewhat more concentrated sludge, and a time of pressing of 3¼ hr., the cake was very wet. The cake obtained in the third test was very wet, and showed signs of becoming septic. In the fourth test, the sludge before pressing was concentrated to 98.5 per cent moisture. The time of pressing was 3½ hr. The cake was wet and septic, consequently the filter cloths were much dirtier. In test 5, 1¼ c.c. of 60 degree Beaumé sulphuric acid were added per gallon of sludge, making a marked improvement in filtering as well as in the physical qualities of the

sludge. Insufficient acid was applied, as the filtrate showed 58 p.p.m. alkalinity.

The results obtained in test 6 were not any better than during the previous runs. In test 7, the sludge was given additional concentration, reducing the moisture content to 98.18 per cent. The best results in this series were obtained with a time of pressing of 3 hr. 52 min., and a cake containing 82.4 per cent moisture.

CONTINUOUS OPERATION, SLUDGE NOT ACIDIFIED. Continuous operation was tried, making 5 pressings, tests 8 to 12 (Table 66). The test started on July 9, 10:02 A. M. and finished July 10, 8:20 A. M., a duration of 22 hr. 18 min. The time was divided as follows:

| Operation | Time | |
|---|---|---|
| | Hr. | Min. |
| Filling Ejector and Starting Press (3 Times) | .... | 21 |
| Pressing—Net | 18 | 6 |
| Removing Water from Ejector (2 Times) | .... | 20 |
| Dumping Press Cake | 1 | 3 |
| Steaming Press (4 Times) | 1 | 38 |
| Lost Between Pressing | .... | 50 |
| Total Time | 22 | 18 |

This is equivalent to a total time consumption per pressing of 4 hr. 28 min. or a net time of actual pressing of 3 hr. 37 min., incidental operations requiring 51 min.

The sludge before pressing contained an average of 98.3 per cent moisture. The press cake contained 85.5 per cent moisture. Considerable sludge adhered to the cloths after each pressing, on account of the wet condition of the cake. Steaming after each run aided considerably but did not stop the difficulty, as Table 66 shows that the porosity of the cloths gradually decreased, thus increasing the time required to collect the first 25 gallons of filtrate. At the end of the fifth pressing, the cloths were so dirty that the test was stopped and the cloths washed.

ADDITION OF ACID. The effect of adding sulphuric acid to the sludge before pressing was then tried. The addition of acid to sludge changes the color to a rich brown, with an accompanying flocculation and coagulation of colloidal matter. Acidified sludge in liquid form does not become septic as rapidly as sludge not acidified. The acid added to the sludge is gradually neutralized

by the alkalinity. The sludge will become alkaline, unless an excessive amount of acid is used. The press cake from acid sludge had an earthy odor, and kept indefinitely without objectionable odor, whether the cake was moist or dry. A very wet cake (without acid) became septic in a comparatively short time in warm weather, while a dry, firm cake did not become odorous even in warm weather.

The sludge for test 13 was treated with 1½ c. c. of 60 deg. Bè. sulphuric acid per gallon of sludge, and was settled for 16 hours before pressing. The sludge became septic on account of the warm weather, and lost its characteristic flocculent appearance. The cake was very wet. The filtrate, although free from suspended sludge, was very cloudy and contained 190 p. p. m. alkalinity. The cloths were allowed to remain in the press, but were steamed and washed with a hose, prior to making the four continuous tests,—14, 15, 16 and 17 (Table 67). The sludge was treated with 1½ c. c. of 60 degree Bè. sulphuric acid. The test started on July 12, 2:16 P. M. and finished July 13, 10:00 A. M., a period of 19 hr. 44 min., divided as follows:

| Operation | Time | |
|---|---|---|
| | Hr. | Min. |
| Filling Ejector and Starting Press (2 Times) | .... | 60 |
| Pressing, Net | 14 | 52 |
| Removing Water from Ejector (2 Times) | .... | 18 |
| Dumping Cake | .... | 45 |
| Steaming (3 Times) | .... | 60 |
| Lost Between Pressing | .... | 49 |
| Total Time | 19 | 44 |

The total time consumed per pressing averaged 4 hr. 56 min. or a net time of 3 hr. 34 min. The sludge before pressing contained 97.9 per cent moisture. The average yield was 87 pounds of press cake with a moisture content of 80.8 per cent. The cake obtained was firm, except for a small wet core, and removable entire, in some instances without disintegrating, leaving the cloths fairly clean. The press was steamed for 20 minutes after each pressing. A slight clogging of the cloths occurred even with steaming, as shown by comparing the time required to collect the first 25 gallons of filtrate. The cloths were fairly clean at the end of the last test, and apparently with steaming between each run would have lasted for several more tests.

# TABLE 66

## ACTIVATED SLUDGE. FILTER PRESSING

Test 1 to 12

| Date 1917 | No. of Test | Time of Pressing | | Percent Moisture | | | Pounds of Cake | Press Liquor | | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Total Gal. | Time to Fill Can (Cap—25 Gal.) Minutes | | | | | | | | | | |
| | | Hr. | Min. | To Press | In Ejector at End of Test | Press Cake | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| MISCELLANEOUS RUN | | | | | | | | | | | | | | | | | | | |
| June 21 | 1 | 4 | 0 | 99.17 | | 89.1 | 72 | 150 | 6 | 24 | 31 | 44 | 45 | 89 | | | | | 6 New Cotton Cloths 6 Old Linen Cloths Cake Very Wet |
| June 22 | 2 | 3 | 15 | 99.01 | | 88.4 | 65 | 108 | 12 | 23 | 45 | 78 | 37* | | | | | | All Cotton Cloths. Cake Very Wet |
| June 25 | 3 | 4 | 12 | 99.13 | 98.80 | 85.3 | 71 | 116 | 12 | 27 | 42 | 82 | 89* | | | | | | Cake Very Wet |
| June 27 | 4 | 3 | 30 | 98.50 | 97.94 | 84.9 | 75 | 92 | 15 | 40 | 70 | 85* | | | | | | | Sludge Septic. Cake Wet |
| June 28 | 5 | 5 | 0 | 99.09 | 99.04 | 86.0 | 73.5 | 221 | 3½ | 10 | 16½ | 22 | 26 | 37 | 47 | 57 | 81* | | Acid Test |
| July 2 | 6 | 3 | 56 | 98.90 | 98.31 | 86.9 | 68 | 104 | 13 | 29 | 50 | 115 | 29* | | | | | | Cake Very Wet |
| July 5 | 7 | 3 | 52 | 98.18 | 97.58 | 82.4 | 84 | 101 | 15 | 36 | 60 | 122 | 19* | | | | | | Cake Fair |
| CONTINUOUS RUN. JULY 9 AND 10 | | | | | | | | | | | | | | | | | | | |
| July 9 | 8 | 3 | 15 | 98.16 | | 85.5 | 81 | 81 | 22 | 48 | 95 | 30* | | | | | | | Cloths All Cotton Cake Wet |
| | 9 | 3 | 45 | 98.16 | | 84.1 | 81 | 68 | 38 | 77 | 118* | | | | | | | | |
| | 10 | 3 | 45 | 98.29 | | 87.5 | 82 | 68 | 35 | 67 | 123* | | | | | | | | |
| July 10 | 11 | 3 | 38 | 98.61 | | 85.2 | 83 | 54 | 44 | 131 | 55* | | | | | | | | |
| | 12 | 3 | 43 | 98.27 | | 85.4 | 79 | 62 | 36 | 75 | 112* | | | | | | | | |
| Total | | 18 | 6 | | | | 406 | 333 | | | | | | | | | | | |
| Average | | 3 | 37 | 98.30 | | 85.5 | 81 | 67 | | | | | | | | | | | |

*Time with respect to the depth of filtrate in last can; 1 in. depth=2 gal.

# TABLE 67

## ACTIVATED SLUDGE. FILTER PRESSING

Tests 13 to 20

| Date 1917 | No. of Test | Time of Pressing | | Percent Moisture | | | Pounds of Cake | Press Liquor | | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Total Gal. | Time to Fill Can (Cap—25 Gal.) Minutes | | | | | | | | | | |
| | | Hr. | Min. | To Press | In Ejector at End of Test | Press Cake | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| July 12 | 13 | 3 | 45 | 98.13 | | 84.5 | 79 | 81 | 22 | 56 | 99 | 48* | | | | | | | Acid Test. Cake Wet |
| July 12 | 14 | 3 | 44 | 97.88 | | 81.9 | 92 | 98 | 17 | 34 | 62 | 122* | | | | | | | Acid Test Cake Good |
| | 15 | 4 | 0 | 97.88 | | 78.5 | 87 | 85 | 26 | 42 | 88 | 83* | | | | | | | |
| July 13 | 16 | 3 | 30 | 97.92 | | 81.2 | 86 | 81 | 21 | 42 | 102 | 45* | | | | | | | |
| | 17 | 3 | 38 | 97.92 | 97.52 | 81.5 | 83 | 58 | 47 | 101 | 77* | | | | | | | | |
| Total | | 14 | 52 | | | | 348 | 322 | | | | | | | | | | | |
| Average | | 3 | 43 | 97.90 | | 80.8 | 87 | 81 | | | | | | | | | | | |
| July 18 | 18 | 3 | 55 | 98.46 | 97.86 | 82.6 | 87 | 112 | 10 | 25 | 40 | 88 | 72* | | | | | | No Acid. Cake Wet. |
| July 18 | 19 | 2 | 28 | 98.70 | | 82.3 | 89 | 148 | 5 | 12 | 22 | 31 | 36 | 42* | | | | | Acid Test. Cake Fair |
| July 20 | 20 | 4 | 0 | 98.48 | 98.35 | 80.8 | 85 | 127 | 9 | 24 | 39 | 46 | 113 | 9* | | | | | Acid Test. Cake Good |

*Time with respect to the depth of filtrate in last can—1 in. depth=2 gal.

In comparing these tests with the earlier ones, the addition of acid resulted as follows:—(1) The yield of sludge-cake was increased. (2) Acidified sludge did not become septic as rapidly. (3) Acidified sludge-cake, even if wet, could be stored without causing a nuisance. (4) Acidified sludge did not clog the filter cloths as rapidly. (5) Acidification increased the nitrogen and fat content of the sludge. The disadvantages of acid treament were:—(1) The cost of treatment was increased. (2) One more step was added to the process. (3) Additional equipment was required for adding the acid.

The average results obtained in continuous tests are given in Table 68, both with the use of acid (runs 13 to 17) and without (runs 9 to 12).

**TABLE 68**

FILTER PRESSING WITH AND WITHOUT ACID

Runs 9 to 12 and 13 to 17, inclusive.

| | Without Acid | With Acid |
|---|---|---|
| Actual Time for Pressing | 3 Hr., 37 Min. | 3 Hr., 43 Min. |
| Percent Moisture—Before Pressing | 98.3 | 97.9 |
| Percent Moisture—Cake | 85.5 | 80.8 |
| Pounds of Cake | 81 | 87 |
| Pounds of Dry Cake | 11.75 | 17.7 |

With practically the same period of operation an increase of 42 per cent (dry pounds) of sludge can be secured from the same press by the addition of 1½ c. c. 60 deg. Be. sulphuric acid per gal. of sludge. Not only is the actual yield greater, but the subsequent cost of drying the cake is reduced, as 1 ton of dry sludge is equivalent to 13,800 lb. of sludge containing 85.5 per cent moisture or 10,400 lb. of sludge containing 80.8 per cent moisture. Thus to produce 1 ton of dry sludge from the cake resulting from treatment without acid, an additional 3,400 lb of water must be evaporated in the dryer.

Test 18 was made without acid, resulting in wet cake. Tests 19 and 20 were made with acidified sludge. In each test 2.0 c. c. 60 deg. Be. sulphuric acid were used per gal. of sludge. The time of pressing in the two tests was 2 hr. 28 min. and 4 hr. respectively. The moisture content in the cake in the 4 hour run was 80.8 per cent, while that in the 2 hr. 28 min. run was 82.3 per cent.

# TABLE 69

ACTIVATED SLUDGE. FILTER PRESSING

Tests 21 to 35

| Date 1917 | No. of Test | Time of Pressing | | Percent Moisture | | | Pounds of Cake | Press Liquor | | | | | | | | | | | Filtrate Rate—Minutes per Gal. at end of | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Total Gal. | Time to Fill Can (Cap.—25 Gal.) Minutes | | | | | | | | | | | | | | | |
| | | Hr. | Min. | To Press | In Ejector at End of Test | Press Cake | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 1 hr. | 1½ hr. | 2 hr. | 2½ hr. | 3 hr. | 3½ hr. |
| **MISCELLANEOUS** | | | | | | | | | | | | | | | | | | | | | | | | |
| Aug. 16 | 21 | 4 | 5 | 98.84 | | 79.0 | 82 | 172 | 4 | 7 | 14 | 20 | 35 | 55 | 110* | | | | | | | | | |
| Aug. 23 | 22* | 3 | 50 | 97.18 | | 78.4 | 80 | 118 | 5 | 12 | 23 | 55 | 135* | | | | | | | | | | | |
| Aug. 30 | 23† | 4 | 1 | 99.34 | | 75.6 | 80 | 225 | 2 | 3 | 6 | 8 | 14 | 24 | 35 | 50 | 99 | | | | | | | |
| Sept. 5 | 24‡ | 3 | 44 | 98.82 | 98.42 | 76.9 | 79 | 193 | 3 | 3 | 8 | 14 | 22 | 35 | 59 | 80* | | | | | | | | |
| Sept. 6 | 25 | 3 | 30 | 98.75 | | 75.9 | 81 | 170 | 2 | 4 | 10 | 19 | 30 | 52 | 93* | | | | | | 3.4 | 4.1 | 4.4 | 7.1 |
| | 26 | 3 | 0 | 98.71 | | 79.1 | 80 | 168 | 2 | 4 | 10 | 18 | 29 | 49 | 68* | | | | | | 3.3 | 4.2 | 4.4 | — |
| | 27 | 2 | 28 | 98.75 | | 80.6 | 79 | 156 | 2 | 4 | 10 | 19 | 30 | 46 | 37* | | | | | | 3.4 | 4.2 | | |
| **CONTINUOUS RUN. TESTS 28 TO 35** | | | | | | | | | | | | | | | | | | | | | | | | |
| Sept. 13 | 28 | 3 | 1 | 98.64 | | 74.2 | 81 | 181 | 2 | 4 | 8 | 14 | 29 | 39 | 64 | 21* | | | | 1.9 | 2.3 | 3.7 | 4.8 | |
| | 29 | 2 | 30 | 98.70 | | 77.0 | 81 | 150 | 2 | 7 | 13 | 22 | 39 | 67 | | | | | | 1.9 | 3.0 | 4.2 | | |
| | 30 | 2 | 27 | 98.72 | | 79.6 | 81 | 158 | 4 | 7 | 9 | 21 | 28 | 54 | 24* | | | | | 1.9 | 2.7 | 4.0 | | |
| | 31 | 2 | 30 | 98.59 | | 78.2 | 80 | 156 | 3 | 7 | 13 | 16 | 32 | 56 | 23* | | | | | 1.9 | 2.7 | 3.9 | | |
| Sept. 13-14 | 32 | 2 | 30 | 98.63 | | 78.4 | 81 | 154 | 3 | 6 | 13 | 21 | 29 | 58 | 20* | | | | | 1.8 | 2.8 | 3.9 | | |
| Sept. 14 | 33 | 2 | 30 | 98.64 | | 77.4 | 81 | 154 | 3 | 6 | 13 | 22 | 31 | 61 | 14* | | | | | 1.9 | 2.7 | 3.9 | | |
| | 34 | 2 | 30 | 98.62 | | 78.3 | 82 | 156 | 3 | 6 | 13 | 23 | 32 | 57 | 16* | | | | | 1.9 | 2.8 | 4.0 | | |
| | 35 | 2 | 37 | 98.60 | | 80.2 | 80. | 148 | 3 | 7 | 19 | 22 | 34 | 72* | | | | | | 1.7 | 2.6 | 4.7 | | |
| Total | | 20 | 35 | | | | 647 | 1257 | | | | | | | | | | | | | | | | |
| Average | | 2 | 34 | 98.64 | | 77.9 | 81 | 157 | | | | | | | | | | | | | | | | |

*Test No. 22—Percent Moisture of cake from section with ribs=75.3

†Test No. 23—New cloths, 9 cotton and 3 linen

‡Test No. 24—4 linen and 8 cotton cloths

PERCENT MOISTURE OF CAKE

| | From 3 Cotton Cloths | From 3 Linen Cloths |
|---|---|---|
| Test No. 30 | 77.4 | 78.5 |
| Test No. 35 | 79.4 | 79.5 |

## PART II.

## TESTS 21 TO 52 INCLUSIVE.

REMODELED PLATES. In tests 21 and 22, one section of the press was fitted with ribs by Mr. W. Buckley, to note the effect on the cake, (Table 69). The cake was firm in both tests. The cake from the ribbed sections was decidedly better than the other cakes, the special cake (test 22) containing 75.4 per cent moisture, as against an average of 78.4 for the other cakes. These results led Mr. Buckley to fit up the entire press with ribs.

Test 23 (Table 69) was the first made with the plates remodeled, using new cloths, 3 linen and 9 cotton. Although the sludge before pressing was very thin (99.34 per cent moisture), the cake was good and contained 75.6 per cent moisture. The time of pressing was 4 hr. 1 min.

In test 24 the sludge used was taken from the main settling tank (not re-aerated), settled for 5 hours, and the supernatant liquid removed. The time of pressing was 3 hr. 44 min. The cake obtained was firm, containing 76.9 per cent moisture.

TIME OF PRESSING. Tests 25, 26 and 27, were conducted with the same sludge, to obtain the relation between the time of pressing and the moisture content of the press cake. (Table 69). The cloths (8 cotton and 4 linen) were cleaned before each pressing. The rate of filtration, measured by the time required to collect 1 gallon of filtrate at half hour intervals, was practically the same for all three tests. (Fig. 21.)

**TABLE 70**

RELATION BETWEEN TIME OF PRESSING AND YIELD

| Pressing Net Time Hr. | Cake | | | Condition of of Cake |
|---|---|---|---|---|
| | Wet Lb. | Percent Moisture | Dry Lb. | |
| 3½ | 81 | 75.9 | 19.5 | Very Good |
| 3 | 80 | 79.1 | 17.5 | Good |
| 2½ | 79 | 80.6 | 15.3 | Fair |

The condition of the filter cloths improved as the time of pressing lengthened.

Assuming ½ hour is consumed (per pressing) in filling ejector, dumping, steaming, etc., the equivalent periods in hours were 4, 3.5 and 3, and the equivalent yield of dry cake was 4.9, 5.0 and 5.1 lb. per hr. respectively.

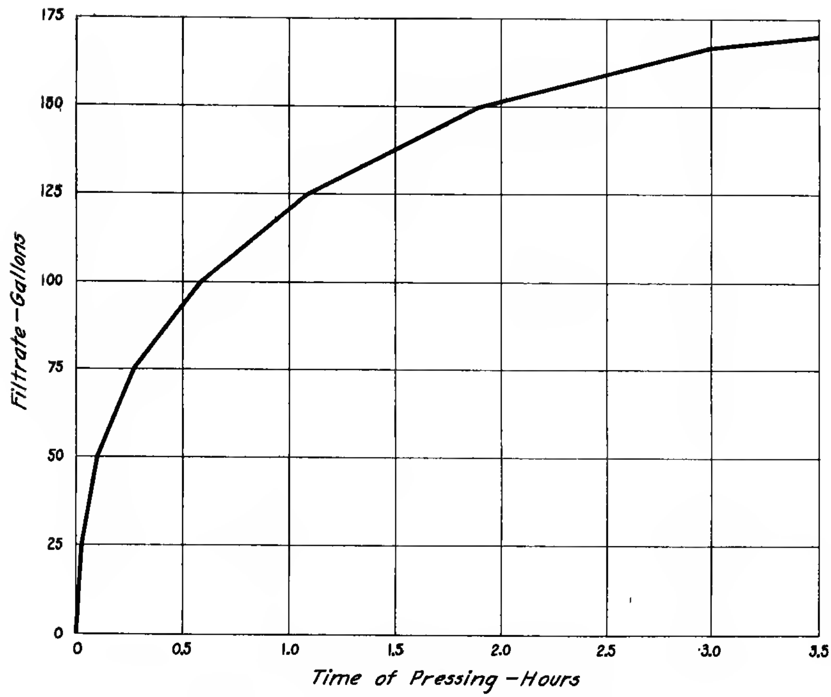


Fig. 21. Rate of Filtration in Filter Press.

On July 13 and 14, a continuous run was made for 8 pressings (tests 28 to 35 inclusive, Table 69). Test 28 was started on July 13, 8:20 A. M., and test 35 was finished July 14, 10:20 A. M., a total elapsed time of 26 hours, of which 20 hr. 35 min. were actually used in pressing. For each pressing the average time was 3 hr. 14 min. gross and 2 hr. 34 min. net.

## TABLE 71

OPERATING DATA ON TESTS 28 TO 35, INCLUSIVE

| Distribution | Time Hr. | Time Min. |
|---|---|---|
| Filling Ejector and Starting Press (7 Times) | .... | 50 |
| Pressing, Net | 20 | 35 |
| Removing Water from Ejector (5 Times) | .... | 44 |
| Dumping Press Cake | 1 | 37 |
| Steaming Press (3 Times) | .... | 30 |
| Inspection and Time Lost Between Pressings | 1 | 44 |

The sludge used was well activated and settled, but contained the screenings, as the screen was not running. Steaming the

cloths for 10 min. after every other test relieved the clogging of the filter cloths (8 cotton and 4 double linen). In tests 30 and 35 press cake from the chambers between the cotton cloths had a moisture content practically the same as cake from the more expensive linen cloths. In all the tests the cake was firm, with a soft center core, and was easily shaken off, leaving over half the area of the cloth fairly clean. The average result per run was 81 lb. of cake containing 77.9 per cent moisture. Table 72 shows the decided improvement on the continuous runs of untreated sludge with the 2 types of plates.

**TABLE 72**

EFFECT OF RIBS ON PRESSING

| | Plate Without Ribs | Plate With Ribs |
|---|---|---|
| Net Time for Pressing | 3 Hr., 37 Min. | 2 Hr., 34 Min. |
| Percent Moisture—To Press | 98.30 | 98.64 |
| Percent Moisture—Cake | 85.5 | 77.9 |
| Pounds of Cake | 81 | 81 |
| Pounds of Dry Cake | 11.75 | 17.9 |

THICKNESS OF CAKE. Tests 36 and 37 were then made to ascertain the most economical thickness of press cake (Table 73). Wooden frames were set in between the plates forming cakes of the following thickness in inches: 1, 1⅛, 1¼ and 1⅜, in addition to the original cake ⅞ in. thick.

The sludge used in test 36 was black, septic and contained hair and screenings. The filter cloths were decidedly dirtier than heretofore, for septic sludge adhered to the cloth like glue, leaving almost the entire cloth dirty. As the cakes increased in thickness, the firmness decreased. About half of the 1⅜ in. cake was soft, and the remainder very wet. The time of pressing was 2 hr. 31 min.

Test 37 was run with a well activated sludge from an unscreened sewage. The time of pressing was 3 hours. The ⅞ in. cake was very firm. The thicker cakes were also good, but the firmness of the cake decreased with the increase in thickness. Although the yield of equivalent dry sludge is greater from the thicker cake, more moisture remains, thereby increasing the expense of drying. The column in Table 73 containing wet pounds of cake is based on the assumption that 80 lb. of ⅞ in. cake are obtained per pressing.

# TABLE 73

ACTIVATED SLUDGE. FILTER PRESSING

TESTS 36 TO 40

| Date 1917 | No. of Test | Time of Pressing | | Percent Moisture | | Thickness of Cake In. | Pounds of Cake | Press Liquor | | | | | | | | | | | | Filtrate Rate Min. per Gal. at end of | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Total Gal. | Time to Fill Can (Cap.—25 Gal.) Minutes | | | | | | | | | | | | | | | | | |
| | | Hr. | Min. | To Press | Press Cake | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 1 hr. | 1½ hr | 2 hr. | 2½ hr. | 3 hr. | 3½ hr. | |
| Sept. 20 | 36 | 2 | 31 | 97.41 | | | 86 | 139 | 3 | 11 | 24 | 33 | 43 | 37* | | | | | | 1.5 | 1.9 | 2.7 | 3.4 | | | |
| | 36 | | | | 77.8 | 7/8 | | | | | | | | | | | | | | | | | | | | Sludge |
| | 36 | | | | 78.5 | 1 | | | | | | | | | | | | | | | | | | | | Septic |
| | 36 | | | | 81.9 | 1 1/8 | | | | | | | | | | | | | | | | | | | | Cloths |
| | 36 | | | | 82.4 | 1 1/4 | | | | | | | | | | | | | | | | | | | | Dirty |
| | 36 | | | | 83.1 | 1 3/8 | | | | | | | | | | | | | | | | | | | | |
| Sept. 21 | 37 | 3 | 0 | 98.37 | | | 92 | 167 | 3 | 6 | 12 | 24 | 34 | 37 | 64* | | | | | 1.3 | 1.8 | 2.3 | 3.8 | 5.5 | | |
| | 37 | | | | 73.9 | 7/8 | | | | | | | | | | | | | | | | | | | | |
| | 37 | | | | 76.3 | 1 | | | | | | | | | | | | | | | | | | | | Cake Good |
| | 37 | | | | 77.6 | 1 1/8 | | | | | | | | | | | | | | | | | | | | |
| | 37 | | | | 78.3 | 1 1/4 | | | | | | | | | | | | | | | | | | | | |
| | 37 | | | | 78.2 | 1 3/8 | | | | | | | | | | | | | | | | | | | | |
| Oct. 2 | 38 | 3 | 15 | 98.52 | | | 112 | 195 | 2 | 7 | 11 | 23 | 27 | 32 | 45 | 48* | | | | 1.2 | 1.4 | 1.7 | | 3.2 | | |
| | 38 | | | | 82.2 | 1 1/4 | | | | | | | | | | | | | | | | | | | | Cake Fair |
| | 38 | | | | 82.2 | 1 5/16 | | | | | | | | | | | | | | | | | | | | |
| | 38 | | | | 83.1 | 1 3/8 | | | | | | | | | | | | | | | | | | | | |
| | 38 | | | | 86.1 | 1 7/16 | | | | | | | | | | | | | | | | | | | | Cake Wet |
| Oct. 4 | 39 | 3 | 30 | 98.66 | | | 114 | 220 | 3 | 6 | 12 | 18 | 24 | 31 | 26 | 45 | 45* | | | 1.2 | 1.3 | 1.4 | 2.1 | 2.2 | 3.1 | |
| | 39 | | | | 82.5 | 1 1/4 | | | | | | | | | | | | | | | | | | | | Without Acid |
| | 39 | | | | 83.0 | 1 7/16 | | | | | | | | | | | | | | | | | | | | |
| | 39 | | | | 83.6 | 1 9/16 | | | | | | | | | | | | | | | | | | | | |
| Oct. 4 | 40 | 3 | 30 | 98.57 | | | 116 | 254 | 2½ | 5½ | 10 | 14 | 18 | 15 | 28 | 32 | 31 | 47 | 7* | 0.9 | 1.2 | 1.3 | 1.5 | 2.0 | 2.4 | With Acid |
| | 40 | | | | 75.7 | 1 1/4 | | | | | | | | | | | | | | | | | | | | |
| | 40 | | | | 82.7 | 1 7/16 | | | | | | | | | | | | | | | | | | | | |
| | 40 | | | | 83.9 | 1 9/16 | | | | | | | | | | | | | | | | | | | | |

*Time with respect to the depth of filtrate in last can. I in. depth = 2 gal.

**TABLE 74**

COMPARISON OF THICKNESS OF PRESS CAKE

| Thickness of Cake Inches | Moisture Percent | Weight of Wet Cake Pounds | Weight of Dry Cake Pounds | Pounds Water to be Evaporated to Produce 1 Ton Dry Cake |
|---|---|---|---|---|
| ⅞ | 73.9 | 80 | 20.9 | 5670 |
| 1 | 76.3 | 91.5 | 21.7 | 6430 |
| 1⅛ | 77.6 | 103 | 23.1 | 6930 |
| 1¼ | 78.3 | 114 | 24.7 | 7220 |
| 1⅜ | 78.2 | 126 | 27.4 | 7180 |

The plates were all remodeled by fastening leather strips $^3/_{16}$ by ¾ in. to the edges, thus increasing the thickness of the cake to 1¼ in.

Test 38 was made with cakes of four different thicknesses, 1¼, $1^5/_{16}$, 1⅜, and $1^7/_{16}$ inches. The 1¼ inch cake was firm only around the edges.

ADDITION OF ACID. Tests 39 and 40 were made on the same sludge with and without the addition of acid. Wooden frames were used in two sections to increase the 1¼ in. cake to $1^7/_{16}$ in. and $1^9/_{16}$ in. Test 39 was made without acid. In test 40, after adding 2 c. c. of 60 deg. Be. sulphuric acid per gallon, the sludge was settled for 3 hours. 380 gallons of supernatant liquid were then removed from 1960 gallons of sludge. The acidified sludge gave up its water much faster (Table 75). In 3 hr. 30 min., the net time of pressing in each test, the acidified sludge gave up 254 gallons of water, while the unacidified sludge gave up 220 gallons.

**TABLE 75**

COMPARISON OF EFFECT OF ACID ON PRESSING

| Filtrate from Press | Test 39 Without Acid | | Test 40 With Acid | |
|---|---|---|---|---|
| Gallons | Hour | Min. | Hour | Min. |
| 25 | .... | 3 | .... | 2½ |
| 50 | .... | 9 | .... | 8 |
| 75 | .... | 21 | .... | 18 |
| 100 | .... | 39 | .... | 32 |
| 125 | 1 | 3 | .... | 50 |
| 150 | 1 | 34 | 1 | 5 |
| 175 | 2 | .... | 1 | 35 |
| 200 | 2 | 45 | 2 | 5 |
| 225 | .... | .... | 2 | 36 |
| 250 | .... | .... | 3 | 23 |

The acidified sludge yielded as much filtrate in 2½ hours as was obtained in 3½ hours without acid, with a press cake weight of 116 lb. as against 114 lb., and a moisture content (1¼ in. cake)

of 75.7 per cent compared with 82.5 per cent respectively. The cloths in the acid run were much cleaner. An improvement is due to acid, assuming the yield at 114 pounds of 1¼ in. cake in each test. (Table 76.)

**TABLE 76**

COMPARISON OF USE OF ACID

| Sludge | Pounds Cake | Percent Moisture | Dry Lb. | Lb. Water to be Evaporated per Ton Dry Sludge |
|---|---|---|---|---|
| Without Acid | 114 | 82.5 | 20 | 9400 |
| With Acid | 114 | 75.7 | 27.7 | 6200 |

The yield of dry sludge is increased 38.5 per cent, in the same period of pressing, and 3200 pounds less of water are required to be evaporated to produce one ton of dry sludge. The cost of acid will depend upon the degree to which the sludge is concentrated before acidification. Table 77 is calculated on the basis of adding 2 c. c. 60 deg. Bè. sulphuric acid to each gallon of sludge, with acid at $15.00 per ton:

**TABLE 77**

COST OF ACID

| Percent Moisture in Sludge | Equivalent Gal. of Sludge per Dry Ton | Acid 60 Deg. Bè. Sulphuric | |
|---|---|---|---|
| | | Lb. per Dry Ton | Dollars per Dry Ton |
| 98.0 | 12,000 | 90 | 0.68 |
| 98.5 | 16,000 | 120 | 0.90 |

Tests 41 and 42 (Table 78) were made with the same sludge, with and without acid. In Test 42, 2 c.c. 60 deg. Bè sulphuric acid were used per gallon of sludge, the sludge being pressed without further concentration. The same amount of filtrate was collected from each test, to obtain press cake of approximately the same moisture content. Test 41, without acid, was run for 4 hours. Only 2 hr. 9 min. were required in Test 42, with acid, in order to collect an equal volume of filtrate. The acid cake was decidedly firmer at the outer edges, though the center was very wet. The filter cloths were much cleaner with the acid sludge. A uniform thickness of cake (1¼ inch) was used. The moisture content of the acid cake was 78.6 per cent, compared with 82.1 per cent for the cake without acid. The effect of the acid shows in Table 79:

# TABLE 78

ACTIVATED SLUDGE. FILTER PRESSING

TESTS 41 TO 52

| Date 1917 | No. of Test | Time of Pressing | | Percent Moisture | | Temp. of Sludge Deg. F. | Pounds of Cake | Press Liquor | | | | | | | | | | | Filtrate Rate Minutes per Gal. at end of | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Time to Fill Can (Cap. 25 Gal.) Minutes | | | | | | | | | | | | | | | | | | |
| | | Hr. | Min. | To Press | Press Cake | | | Total Gal. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 1 hr. | 1½ hr. | 2 hr. | 2½ hr | 3 hr. | 3½ hr. | 4 hr. | 4½ hr. | |
| Oct 9 | 41 | 4 | 0 | 98.91 | 82.1 | 52 | 111 | 225 | 3 | 6 | 12 | 16 | 23 | 28 | 34 | 37 | 81 | .... | 1.2 | 1.5 | 1.8 | 2.1 | 2.7 | 3.7 | 4.6 | .... | Without Acid |
| Oct. 11 | 42 | 2 | 9 | 98.83 | 78.6 | .... | 109 | 225 | 2 | 5 | 8 | 12 | 15 | 18 | 21 | 24 | 24 | .... | 0.9 | 0.9 | 1.1 | .... | .... | .... | .... | .... | With Acid |
| Oct. 26 | 43 | 3 | 31 | 98.84 | 87.6 | 45 | 104 | 160 | 4 | 11 | 20 | 29 | 44 | 65 | 38* | .... | .... | .... | 2.1 | 2.4 | 2.4 | 3.3 | 3.7 | 4.4 | .... | .... | Sludge Not |
| Oct. 27 | 44 | 4 | 0 | 98.80 | 88.0 | 43 | 110 | 186 | 4 | 10 | 22 | 30 | 34 | 45 | 55 | 40* | .... | .... | 1.4 | 1.9 | 2.3 | 2.5 | 3.3 | 4.2 | 4.8 | .... | Typical |
| Oct. 29 | 45 | 4 | 30 | 98.75 | 85.4 | 43 | 107 | 180 | 3 | 9 | 32 | 36 | 40 | 55 | 77 | 18* | .... | .... | 1.7 | 2.0 | 2.4 | 2.8 | 3.3 | 3.5 | 4.7 | 5.2 | |
| Nov. 7 | 46 | 4 | 4 | 98.38 | 82.6 | 47 | 112 | 154 | 3 | 12 | 35 | 42 | 53 | 85 | 14* | .... | .... | .... | 1.9 | 2.1 | 2.5 | 3.6 | 4.2 | 4.7 | 5.4 | .... | No Acid |
| Nov. 8 | 47 | 2 | 45 | 98.25 | 82.4 | .... | 110 | 154 | 4 | 14 | 30 | 33 | 33 | 43 | 8* | .... | .... | .... | 1.3 | 1.5 | 1.9 | 2.5 | .... | .... | .... | .... | Sherwin-Williams |
| Nov. 9 | 48 | 3 | 0 | 98.88 | 77.7 | 58 | 101 | 282 | 2 | 3 | 6 | 9 | 11 | 16 | 18 | 25 | 18 | 25 | 0.9 | 1.2 | 1.1 | 1.7 | 2.2 | .... | .... | .... | Acid Waste |
| | | | | | | | | | | | | | | | 1 | 1th | 12 | th | | | | | | | | | |
| | | | | | | | | | | | | | | | | 36 | 11* | | | | | | | | | | |
| Nov. 10 | 49 | 4 | 0 | 98.81 | 84.8 | 57 | 108 | 208 | 3 | 6 | 11 | 20 | 32 | 33 | 42 | 68 | 25 | *.... | 1.4 | 1.8 | 2.1 | 2.8 | 3.8 | 4.0 | 4.9 | .... | No Acid |
| Nov. 10 | 50 | 2 | 28 | 98.66 | 74.3 | 58 | 106 | 208 | 2 | 4 | 9 | 12 | 24 | 29 | 28 | 33 | 7* | .... | 1.6 | 1.8 | 1.9 | 2.0 | .... | .... | .... | .... | Sherwin Williams Acid Waste |
| Nov. 12 | 51 | 3 | 0 | 98.58 | 87.2 | 53 | 97 | 187 | 2 | 9 | 11 | 14 | 20 | 33 | 56 | 35* | .... | .... | 1.3 | 2.0 | 3.7 | 4.2 | 4.8 | .... | .... | .... | Niter Cake |
| Nov. 16 | 52 | 3 | 0 | 98.16 | 79.9 | 57 | 102 | 169 | 3 | 10 | 18 | 31 | 47 | 34 | 37* | .... | .... | .... | 1.7 | 2.2 | 2.2 | 2.3 | 3.2 | .... | .... | .... | |

*Time with respect to the depth of filtrate in last can—1 in. depth = 2 gal.

Filtrate Test 48

| Determination | P. P. M. | |
|---|---|---|
| Nitrogen as | Free $NH_3$ | 12.8 |
| | Org. N | 17.6 |
| | Nitrites | 0.36 |
| | Nitrates | 1.76 |

Taking ½ hour as the time required per pressing for filling, dumping and steaming, the time ratio would be 4 hr. 30 min. to 2 hr. 39 min. These figures indicate that 4.4 dry lb. per hr. could be obtained from pressing without acid, while 8.8 dry lb. per hr. could be obtained with acid. This indicates the yield could be increased 100 per cent by the use of acid. At the same time the press cake would have a lower moisture content thus reducing the cost of drying as the amount of water to be evaporated per ton of dry sludge is 1850 lb. less.

**TABLE 79**

COMPARISON OF USE OF ACID

| Sludge | Net Time Pressing | | Cake | | Dry Lb. | Lb. Water to be Evaporated per Ton Dry Sludge |
|---|---|---|---|---|---|---|
| | Hr. | Min. | Lb. | Percent Moisture | | |
| Without Acid | 4 | .... | 111 | 82.1 | 19.9 | 9200 |
| With Acid | 2 | 9 | 109 | 78.6 | 23.3 | 7350 |

TESTS WITH OVER-AERATED SLUDGE. Tests 43, 44 and 45 were made with the same sludge, and respective periods of pressing—3½ hr., 4 hr., and 4½ hr. This sludge had been aerated for some time, and was not a typical activated sludge. In Test 43, the pressure increased very rapidly from 15 to 100 lb. per sq. in. within a half hour. The filtrate in tests 44 and 45 was greater in volume than in 43, for equivalent time intervals. The press cake in all three tests was very wet. The filter cloths were rather dirty. The yields are compared in Table 80. The yield of dry pounds is lower than with the thinner cake, because of the condition of the sludge.

**TABLE 80**

COMPARISON OF YIELD AND TIME OF PRESSING

| Net Time Pressing Hr. | Cake | | | Condition |
|---|---|---|---|---|
| | Wet Pounds | Moisture Percent | Dry Pounds | |
| 3.5 | 104 | 87.6 | 12.9 | Very Wet |
| 4.0 | 110 | 88.0 | 13.2 | Very Wet |
| 4.5 | 107 | 85.4 | 15.6 | Very Wet |

ADDITION OF DYE-FACTORY ACID WASTE. Tests 46, 47 and 48 were made to determine the value of an acid waste obtained from the dye plant of the Sherwin-Williams Paint Co. This waste contained 72.62 per cent of free sulphuric acid, and had a specific gravity of 1.686. Test 46 and 47 were made with the

same sludge except that in test 47, 2 c. c. of acid waste were used per gallon of sludge. As the same sludge was used, the tests were run to obtain the same volume of filtrate. The acidified cake was much firmer on the outer edges and along the ribs, but softer in the center. The acidified cake was decidedly darker in color, with an odor similar to the acid waste. The sludge used in test 48 was concentrated by settling for 4¾ hr. and was very dilute, containing 98.88 per cent moisture. In this test 3 c. c. of the acid waste were used per gallon of sludge, making the sludge very brown, flocculent and foamy. The filtrate was exceptionally clear and in amount exceptionally large, 150 gallons during the first 47 minutes. A sample of the filtrate was collected for chemical analyses (Table 80). The cake obtained was good (Table 81).

**TABLE 81**

ACIDIFICATION WITH DYE-FACTORY WASTE

| Test No. | Acid Waste c.c. per Gal. | Time Pressing* | | Cake | | | Dry Sludge Lb. per Hr. | Lb. Water to be Evaporated per Dry Ton |
|---|---|---|---|---|---|---|---|---|
| | | Hr. | Min. | Wet Lb. | Moisture Percent | Dry Lb. | | |
| 46 | None | 4 | 34 | 112 | 82.6 | 19.5 | 4.2 | 9,500 |
| 47 | 2 | 3 | 15 | 110 | 82.4 | 19.4 | 6.0 | 9,300 |
| 48 | 3 | 3 | 30 | 101 | 77.7 | 22.5 | 6.4 | 7,000 |

*Times given are net times plus one-half hour.

Tests 49 and 50 were made on the same sludge, with and without the acid waste. Test 49 was run for 4 hours. The cake obtained was rather wet, the cloths being fairly dirty. In test 50, 3 c. c. of the acid waste were added per gallon. The pressing was continued until a volume of filtrate was obtained equal to that from the unacidified sludge. The acid cake, however, was much firmer, and the cloths cleaner. The tests are compared in Table 82.

**TABLE 82**

COMPARISON OF USE OF DYE-FACTORY WASTE

| Sludge | Time Pressing* | | Cake | | | Dry Sludge Lb. per Hr. | Lb. Water to be Evaporated |
|---|---|---|---|---|---|---|---|
| | Hr. | Min. | Lb. | Percent Moisture | Dry Lb. | | |
| Without Acid | 4 | 30 | 108 | 84.8 | 16.4 | 3.7 | 11,200 |
| With Acid | 2 | 58 | 106 | 74.3 | 27.3 | 9.2 | 5,800 |

*Times given are net times plus one-half hour.

This test indicated that the use of acid waste increased the effectiveness of the press by 150 per cent.

ADDITION OF NITRE CAKE. In tests 51 and 52, the sludge was treated with nitre cake obtained from the Du Pont Powder Co. The nitre cake on analysis was found to contain 32.42 per cent free sulphuric acid, with a total $SO_3$ content of 62.18 per cent. In test 51, one pound of nitre cake was added to 57 gallons of sludge, an equivalent of of 210 lb. per 12,000 gallons of sludge, or the equivalent of 90 lb. of 60 deg. Be. acid per 12,000 gallons of sludge. At first some of the nitre cake was lost, because of the crude method of application, by moving a burlap bag full of lumps through the sludge. As this worked poorly, the wet lumps were pulverized and added to the aerating sludge. The filter cloths were in very poor condition, passing considerable sludge to the filtrate. Test 52 was then run for 3 hours with 1 lb. nitre cake per 30 gal. of sludge (equivalent to 400 lb. nitre cake per 12,000 gal. sludge). The nitre cake was pulverized and dissolved in water to avoid any loss. The filtrate contained considerable sludge because of torn cloths, but the press cake was firm.

CHEMICAL ANALYSES OF SLUDGE. Analyses were made of the liquid sludge and press cake, with and without acid treatment (Table 83). In comparing the analyses of the same sludge before and after pressing, tests 14 and 17 are typical. The fixed matter is apparently 10.5 per cent higher in the liquid sludge, due largely to the method of determination which includes the dissolved solids. The higher organic nitrogen in the press cake is in part due to the same fact. The analyses of the press cake are more representative than those of the liquid sludge.

The analyses of the press cake with and without acid treatment, comparing an average of 10 analyses of each, show that the total nitrogen apparently increased 0.78 per cent and the ether soluble 2.18 per cent in the acid samples. The increase in ether soluble matter is due to the liberation of fatty acids from soaps. Possibly the increase of organic nitrogen is due to the flocculation produced by the addition of acid thereby coagulating the colloidal matter, high in nitrogen which is retained in the sludge, leaving a very clear filtrate after pressing.

Samples of press cake from test 39 (without acid) and 40 (with acid) were analyzed by the chemists of Swift and Company and Armour and Company (Table 84). The availability of the nitrogen

# TABLE 83

ACTIVATED SLUDGE. ANALYSES OF SLUDGE AND PRESS CAKE

June 28 to November 12, 1917

| Date 1917 | No. of Test | Sp. Gr. | Percent Moisture | Percent | | Percent Organic Nitrogen | Ether Soluble Percent | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Volatile Matter | Fixed Matter | | Non-Acid | Acidified | |
| June 28 | 5 | 1.007 | 99.19 | 62.4 | 37.6 | 4.16 | 6.02 | 6.98 | TC before acid added |
| | 5 | 1.07 | 86.0 | 79.4 | 20.6 | 7.04 | 7.34 | 7.78 | Press cake—acid |
| July 9 | 8–12 | ........ | 98.30 | 72.0 | 28.0 | 4.32 | ........ | ........ | To press |
| July 9–10 | 8–12 | ........ | 85.5 | 75.7 | 24.3 | 5.04 | 3.72 | 6.30 | Composite press cake |
| July 12 | 14–17 | 1.02 | 98.01 | 69.0 | 31.0 | 4.16 | 6.04 | 6.74 | TC Acid Sludge |
| July 12–13 | 14–17 | ........ | 80.8 | 80.5 | 19.5 | 6.80 | 5.94 | 6.22 | Composite press cake |
| July 18 | 18 | 1.07 | 82.6 | 78.9 | 21.1 | 6.08 | 5.54 | 5.68 | Press cake |
| July 19 | 19 | 1.07 | 82.3 | 79.3 | 20.7 | 5.60 | 6.12 | 7.50 | Press cake |
| July 20 | 20 | ........ | 80.8 | ........ | ........ | 6.08 | ........ | ........ | Press cake |
| Sept. 6 | 25–27 | ........ | 78.5 | 73.8 | 26.2 | 4.88 | 3.20 | 3.84 | Composite press cake |
| Sept. 21 | 37 | ........ | 76.9 | 73.8 | 26.2 | 4.80 | 3.12 | 4.44 | Press cake |
| Oct. 4 | 39 | ........ | 83.0 | 76.8 | 23.2 | 5.36 | 1.30 | 1.66 | Press cake |
| Oct. 4 | 40 | 1.02 | 98.80 | 64.9 | 35.1 | 3.60 | 3.10 | 3.90 | Sludge before acid added |
| | 40 | ........ | 80.8 | 81.4 | 18.6 | 5.76 | 3.12 | 3.68 | Press cake |
| Oct. 9 | 41 | ........ | 82.1 | 79.1 | 20.9 | 5.12 | 3.68 | 4.64 | Press cake |
| Oct 11 | 42 | ........ | 78.6 | 82.0 | 18.0 | 5.76 | 3.20 | 3.72 | Press cake |
| Oct. 27 | 44 | 1.06 | 88.0 | 77.2 | 22.8 | 4.80 | 2.34 | 3.12 | Press cake |
| Oct. 29 | 45 | 1.06 | 85.4 | 77.0 | 23.0 | 5.28 | 2.58 | 3.94 | Press cake |
| Nov. 7 | 46 | 1.07 | 82.6 | 75.9 | 24.1 | 4.64 | 6.24 | 6.52 | Press cake |
| Nov. 8 | 47 | 1.06 | 82.4 | 78.6 | 21.4 | 4.96 | 4.94 | 5.00 | Press cake |
| Nov 9 | 48 | ........ | 77.7 | 81.8 | 18.2 | 5.60 | 5.96 | 7.84 | Press cake |
| Nov. 10 | 49 | ........ | 84.8 | 81.9 | 18.1 | 4.80 | 3.86 | 9.08 | Press cake |
| Nov 10 | 50 | ........ | 74.3 | 85.3 | 14.7 | 5.28 | 6.26 | 7.48 | Press cake |
| Nov. 12 | 51 | 1.06 | 87.2 | 83.2 | 16.8 | 5.60 | 7.22 | 8.10 | Press cake |

Average Percent Organic Nitrogen (10 Analyses of Each) { Acid Cake=5.85, Cake (No Acid)=5.08 } —Diff.=0.78 Percent

Average Percent Ether Soluble (9 Analyses of Each) { Acid Cake=5.85, Cake (No Acid)=3.67 } —Diff.=2.18

in the acid sludge cake was found to be higher by the two standard methods of analyses. However, the per cent of potash and phosphoric acid is slightly lower in the acid sludge cake.

TABLE 84

ACTIVATED SLUDGE. COMPARATIVE ANALYSES OF PRESS CAKE

Sanitary District, Swift, and Armour

| | The Sanitary District of Chicago | | Swift & Co. | | Armour & Co. | |
|---|---|---|---|---|---|---|
| | Test 39 | Test 40 Acid | Test 39 | Test 40 Acid | Test 39 | Test 40 Acid |
| Moisture | 83.0 | 80.8 | 83.0 | 80.7 | 83.01 | 75.38 |
| Dry Basis | | | | | | |
| Volatile Matter | 76.8 | 81.4 | ....... | ....... | ....... | ....... |
| Fixed Matter | 23.2 | 18.6 | ....... | ....... | ....... | ....... |
| Nitrogen, Total | 5.36 | 5.76 | 5.65 | 6.12 | 5.11 | 6.15 |
| Equivalent to Ammonia, | | | | | | |
| Total | 6.50 | 6.99 | 6.87 | 7.42 | 6.24 | 7.33 |
| Water Soluble | ....... | ....... | ....... | ....... | 1.23 | 1.01 |
| Water Insoluble Organic | ....... | ....... | ....... | ....... | 5.01 | 6.32 |
| Available (KMnO4 Neutral) | ....... | ....... | ....... | ....... | 2.59 | 3.92 |
| Percent Availability | ....... | ....... | ....... | ....... | 51.8 | 62.1 |
| Available (KMnO4 Alkaline) | ....... | ....... | ....... | ....... | 1.93 | 2.83 |
| Percent Availability | ....... | ....... | ....... | ....... | 38.9 | 44.8 |
| Phosphoric Acid Available | ....... | ....... | 2.06 | 1.45 | 1.88 | 1.21 |
| Acid Insoluble | ....... | ....... | 0.53 | 0.47 | 0.35 | 0.20 |
| Total | ....... | ....... | 2.59 | 1.92 | 2.23 | 1.41 |
| Water—Soluble Potash | ....... | ....... | 0.35 | 0.16 | 0.47 | 0.32 |
| Fat | 1.30 | 3.12 | 3.18 | 3.58 | 0.41 | 2.60 |

CONCLUSIONS. The results of these experiments indicated that activated sludge from stockyards sewage could be filter pressed successfully without the use of lime in the standard type plate press. The time of pressing was materially shortened by providing a sludge well activated, with the characteristic physical appearance. The presence of screenings in the sludge aided in the pressing. The more concentrated the sludge within the limits investigated, the shorter was the time of pressing and the better the results. Sludge given a preliminary settling usually contained 98.0 to 98.5 per cent moisture.

Cotton duck cloths were found to give as satisfactory results as linen cloths, although an extended comparison of the difference in the life of the cloths was not made. During the fifty-two tests, two complete sets of cotton duck cloths were used, one set being used for the first twenty tests.

The addition of ribs made a sectional plate, forming the cake in smaller sections, and increasing the relative drainage area as compared to cake area. The improvement was very pronounced, as shown by the continuous runs made with each type of plate.

If the results of continuous runs with each type of plate be compared on the basis of ⅞ inch cake and a time of pressing arrived at by adding one-half hour to the net time of pressing, the original plate produced 2.85 dry lb. per hr., while the improved type of plate produced 5.95 dry lb. per hr., with moisture contents of 85.5 and 77.9 per cent respectively.

From a series of tests made to determine the most economical time of pressing with a ⅞ inch cake, 4 per cent more yield (dry lb. per hr.) was obtained in the 3 hour run (total time) than in the 4 hour run but the press cake in the shorter run contained more moisture. If 8 pressings were made at 3 hours each as compared with 6 pressings at 4 hours each, the cost of filter cloths per dry ton of sludge would probably be greater with the shorter pressing.

The most economical thickness of cake was studied, with the thickness of cake varying from ⅞ to $1^9/_{16}$ inch. The results indicate that although the yield increased with the thickness of the cake, the moisture content also increased, thus adding to the amount of moisture to be evaporated. About one inch seemed the most practical thickness.

The addition of sulphuric acid changed the color of the sludge to a rich brown, coagulated the colloidal material and flocculated the sludge, making it easier to filter press. Acidified sludge did not become septic as rapidly as sludge without acid. The advantages of the addition of acid as a preliminary treatment to filter pressing were:

1. The yield and capacity of press are increased.
2. The nitrogen and fat content of the sludge are increased.
3. The filter cloths do not clog as rapidly.
4. The sludge cake does not become septic on storage.

The only objections to the use of acid were:

1. The cost of the acid.
2. The addition of another step in the process, as well as the requirement of more equipment.

A comparison was made on the same sludge with and without the addition of acid, with a cake 1¼ inch thick, and the use of 2 c. c. of 60 deg. Be. sulphuric acid per gallon of sludge in the acid tests. With a net pressing time of 2.5 hr. in both tests, the yield of cake was increased 38.5 per cent in the acid test. The moisture content of the acid sludge was 75.7 per cent, of the unacidified

sludge 82.5 per cent. With different relative pressing periods, namely 4 hr. without acid and 2 hr. 9 min. with acid, the same yield can be obtained with half of the number of presses with the acid sludge, and the evaporation of 1850 lb. of water would be saved per ton of dry sludge. The cost of acid depends upon the concentration of the sludge treated. Assuming the price of 60 deg. Bè sulphuric acid to be $15.00 per ton, and that 2 c. c. acid per gal. of sludge are used, the cost of acid per dry ton of sludge would be $0.68 with a sludge containing 98.0 per cent moisture, and $0.90 with a sludge containing 98.5 per cent moisture.

An acid waste liquor containing 72.62 per cent free acid (equivalent to an acid of about 57 degrees Bè.) was obtained from the dye plant of Sherwin-Williams Paint Co. This waste gave satisfactory results when used in amounts of 2 to 3 c. c. per gal. of sludge. Nitre cake containing 33 per cent free acid was also tried, with equally good results. Nitre cake has advantages over sulphuric acid, as it can be shipped in bulk in boxes, is easier to store and apply, and is less dangerous to handle. The relative economy of acid vs. nitre cake will vary according to conditions and location.

The acid sludge apparently has a higher nitrogen content than unacidified sludge. Analyses of press cake indicated that the actual nitrogen recovered in dried press cake would be greater than indicated by analyses of wet sludge as taken from the tanks, due to the larger proportion of dissolved inorganic solids incorporated in the dried sludge than in the tanks. This increase would amount to approximately 10 per cent.

## CHAPTER XI.

## SCREENING TESTS.

GENERAL. The rotary screen used in all tests was the one used in 1913 and 1914. This was operated from 7 A. M. to 9 P. M., except on Sundays and holidays.

RESULTS WITH 30 MESH SCREEN. A 30 mesh brass wire screen was used from July 1, 1916, to May 4, 1917, with the exception of a period of four weeks, from September 17 to October 14, 1916. Considerable difficulty was experienced with clogging, especially during the early part of July, when an average of only 230 lb. of dry screenings were removed per million gallons of sewage screened. During the latter part of July and early August, better results were obtained by washing the screen occasionally with water under pressure, in addition to the regular automatic washing. During the end of August and in early September, the screen was regularly scrubbed on Sunday with a hot solution of soda ash. This removed the grease which clogged the openings of the screen, and practically eliminated all difficulty from clogging. In August, an average of 516 lb., and from September 1 to 17, an average of 620 lb. of dry screenings were obtained per million gallons of sewage. The increased retention was probably due to the improved efficiency of the screen, caused by cleaning.

The operating results (Table 85) show a marked increase in the recovery during the cold weather, reaching a maximum during the period Nov. 24, 1916 to Jan. 8, 1917, when an average of 1280 lb. of dry screenings was obtained per mil. gal. of sewage. This increase was due to the greater strength of the crude sewage during this period. The results indicate a very high use of water, 10.5 to 29.0 percent for washing purposes on the daily routine during the time the screen was actually running. Undoubtedly a larger screen of this type could readily be cleaned with a lower use of wash water. Large screens should be fitted with facilities for cleaning with steam, as a screen of 30 mesh clogs very rapidly.

# TABLE 85

ROTARY SCREEN OPERATING DATA. 30-MESH

July 1, 1916, to May 3, 1917

| Dates Inclusive | Total Gallons Treated | Percent Wash Water | Wet Screenings Total Lbs. | Percent Moisture | Dry Screenings Total Lbs. | Screenings as Susp. Solids P.P M. | Total Susp. Solids in Screen Effluent P.P.M. | Total Susp. Solids Crude Sewage Computed P.P.M. | Percent Reduction Susp. Solids |
|---|---|---|---|---|---|---|---|---|---|
| July 1 to 31 | 762,300 | 12.4 | 825 | 78.8 | 175 | 28 | 353 | 381 | 7.4 |
| Aug. 1 to 31 | 1,004,900 | 12.7 | 2,540 | 79.7 | 516 | 62 | 367 | 429 | 14.4 |
| Sept. 1 to 16 | 496,700 | 15.8 | 1,600 | 80.8 | 307 | 74 | 380 | 454 | 16.3 |
| Oct. 15 to 23 | 227,900 | 16.5 | 895 | 80.2 | 177 | 93 | 490 | 58[illegible] | 16.0 |
| Oct. 24 to Nov. 24 | 1,205,900 | 10.5 | 6,470 | 81.8 | 1,177 | 117 | 532 | 649 | 18.1 |
| Nov. 25 to Jan. 8, 1917 | 1,358,400 | 12.1 | 10,420 | 83.3 | 1,740 | 153 | 542 | 695 | 22.0 |
| Jan. 9 to Feb. 4 | 627,400 | 21.5 | 4,090 | 81.6 | 753 | 144 | 465 | 609 | 23.6 |
| Feb. 5 to Mar. 5 | 618,800 | 18.0 | 2,520 | 80.8 | 485 | 94 | 480 | 574 | 16.4 |
| Mar 6 to Mar. 26 | 392,200 | 29.0 | 2,420 | 79.6 | 494 | 151 | 427 | 578 | 26.2 |
| Mar. 22 to April 22 | 811,500 | 22.6 | 2,810 | 79.3 | 582 | 86 | 407 | 493 | 17.5 |
| April 23 to May 3 | 282,800 | 26.4 | 1,200 | 77.3 | 273 | 116 | 354 | 470 | 24.7 |
| Total | 7,788,800 | ...... | 35,790 | ...... | 6,679 | ...... | ...... | ...... | ...... |
| Average | ...... | 18.0 | ...... | 81.2 | ...... | 103 | 444 | 547 | 18.8 |

## TABLE 86

ROTARY SCREEN. OPERATING DATA. 20-MESH

May 21 to Nov. 14, 1917

| Dates Inclusive | Total Gallons Treated | Percent Wash Water | Wet Screenings Total Lbs. | Percent Moisture | Dry Screenings Total Lbs. | Screenings as Susp. Solids P.P.M. | Total Susp. Solids in Screen Effluent P.P.M. | Total Susp. Solids in Crude Sewage Computed P.P.M. | Per cent Reduction Susp. Solids |
|---|---|---|---|---|---|---|---|---|---|
| May 21 to July 1, 1917 | 1,172,800 | 19.5 | 1,660 | 78.7 | 353 | 36 | 370 | 406 | 8.9 |
| July 2 to July 31 | 925,100 | 13.6 | 1,090 | 78.7 | 232 | 30 | 414 | 444 | 6.8 |
| Aug. 1 to Aug. 31 | 876,970 | 14.9 | 1,040 | 78.8 | 220 | 30 | 397 | 427 | 7.0 |
| Sept. 1 to Sept. 22 | 225,510 | 12.8 | 285 | 80.7 | 55 | 29 | 509 | 538 | 5.4 |
| Sept. 24 to Oct. 12 | 687,590 | 13.7 | 1,235 | 80.0 | 247 | 43 | 438 | 481 | 8.9 |
| Oct. 13 to Oct. 21 | 306,600 | 13.7 | 840 | 81.5 | 155 | 61 | 573 | 634 | 9.6 |
| Oct. 22 to Nov. 14 | 881,600 | 11.8 | 3,600 | 83.3 | 601 | 82 | 421 | 503 | 16.3 |
| Total | 5,076,170 | ........ | 9,750 | ........ | 1,863 | ........ | ........ | ........ | ........ |
| Average | ........ | 14.3 | ........ | 80.9 | ........ | 44 | 416 | 460 | 9.6 |

RESULTS WITH 20 MESH SCREEN. The 30 mesh screen was replaced by a 20 mesh in May, 1917. This was used from May 21 to November 14, 1917, with no interruptions, and no trouble from clogging. The operating results are summarized in Table 86. As in 1916, an increasing removal of screenings was noted as cold weather approached. The consumption of wash water was lower than in 1916, averaging 14.3 per cent as compared with 18.0 per cent in the period July 1, 1916 to May 3, 1917.

COMPARISON OF RESULTS, 20 AND 30 MESH. The 30 mesh screen was operated for 224 days, screening about 6 million gallons of sewage. A recovery of 858 lb. of dry screenings was obtained per million gallons of sewage screened, equivalent to a reduction of 18.8 per cent of the total suspended solids.

The 20 mesh screen was operated for 138 days, screening 5 million gallons of sewage. A recovery of 368 lb. of dry screenings was obtained per million gallons of sewage screened, equivalent to a reduction of 9.6 per cent of the total suspended solids.

The comparatively greater efficiency of the finer screen is somewhat exaggerated, as the test with the 30 mesh screen was run on a crude sewage containing 547 p. p. m. total suspended solids, while the test with the 20 mesh screen was run on a crude sewage containing only 460 p. p. m. total suspended solids.

CHARACTER AND ANALYSES OF SCREENINGS. The screenings removed from Packingtown sewage consist largely of hay, chaff, paunch manure, undigested food particles, hair, bits of skin and flesh, etc. While the screen was shut down (Sept. 17 to Oct. 14, 1916) the material ordinarily removed by the screen passed through the aerating tanks in an unchanged condition, requiring additional air to prevent settling on the filtros plates.

The analyses of weekly composites, from Oct. 16, 1916 to Jan. 6, 1917, are given in Table 87. Moisture content was determined on the mixed sample after drying on the steam bath, and has no relation to the original moisture content of the screenings, which was 80.7 per cent.

The dry screenings were largely of organic nature averaging only 4.7 per cent of mineral matter, with total nitrogen only 2.18 per cent. The ether soluble content was 5.93 per cent, with an increase to 9.38 per cent upon acidification.

In 1917, while the 20 mesh screen was being used, only mois-

## TABLE 87

ROTARY SCREEN. ANALYSES OF SCREENINGS

| Date | Percent Moisture (Air-Dry) | Calculated to Dry Weight—Percent | | | | | Remarks |
|---|---|---|---|---|---|---|---|
| | | Fixed Matter | Volatile Matter | Organic Nitrogen | Ether Soluble | | |
| | | | | | | Acidified | |
| 1916 | | | | | | | |
| Oct. 16 to 21 | 5.6 | 5.9 | 94.1 | 2.08 | 4.96 | 6.50 | |
| Oct. 23 to 28 | 6.9 | 6.2 | 93.8 | 1.92 | 6.74 | 9.04 | |
| Oct. 30 to Nov. 4 | 6.2 | 5.4 | 94.6 | 2.56 | 5.46 | 7.40 | $P_2O_5$=0.40; $K_2O$=0.28 |
| Nov. 6 to 11 | 6.1 | 3.1 | 96.9 | 2.08 | 6.02 | 9.72 | |
| 13 to 18 | 7.3 | 3.7 | 96.3 | 2.24 | 5.34 | 9.34 | |
| 20 to 25 | 6.8 | 4.4 | 95.6 | 2.40 | 5.06 | 9.22 | |
| 27 to Dec. 2 | 6.76 | 4.7 | 95.3 | 1.76 | 3.72 | 7.64 | $P_2O_5$=0.30; $K_2O$=0.35 |
| Dec. 4 to 9 | 3.0 | 5.0 | 95.0 | 1.76 | 6.64 | 10.18 | |
| 11 to 16 | 5.58 | 7.6 | 92.4 | 2.08 | 5.44 | 9.10 | |
| 18 to 23 | 5.85 | 5.0 | 95.0 | 2.56 | 8.30 | 12.28 | |
| 26 to 30 | 2.26 | 3.9 | 96.1 | 2.72 | 7.02 | 12.38 | |
| 1917 | | | | | | | |
| Jan. 2 to 6 | 8.84 | 2.2 | 97.8 | 2.08 | 6.54 | 9.80 | |
| Average | 5.9 | 4.7 | 95.3 | 2.18 | 5.93 | 9.38 | |

ture determinations were made. The average of all such daily determinations was 80.9 per cent, almost exactly the same as the 81.2 per cent moisture found in the screenings from the 30 mesh screen.

BI-HOURLY VARIATIONS. A special test was made with the 30 mesh screen from March 22 to 27, 1915, to determine the variation in results throughout the day. Composites were made up for 2 hour periods throughout the day, from 7:30 A. M. to 9:30 P. M. The reduction in suspended solids is shown in Table 88.

**TABLE 88**

REDUCTION IN SUSPENDED MATTER BY FINE SCREENING

Two Hour Periods—Mar. 22 to 27, 1915

| Time | Suspended Matter Parts per Mil. | | Percent Reduction |
|---|---|---|---|
| | Influent | Effluent | |
| 7:30 a. m. to 9:30 a. m. | 413 | 377 | 9 |
| 9:30 a. m. to 11:30 a. m. | 462 | 397 | 14 |
| 11:30 a. m. to 1:30 p. m. | 479 | 426 | 11 |
| 1:30 p. m. to 3:30 p. m. | 492 | 420 | 15 |
| 3:30 p. m. to 5:30 p. m. | 582 | 500 | 14 |
| 5:30 p. m. to 7:30 p m. | 394 | 317 | 19 |
| 7:30 p. m. to 9:30 p. m. | 201 | 182 | 10 |
| Average | 434 | 374 | 14 |

## SCREENING.

The per cent reduction in suspended solids is fairly constant throughout the day, but the actual weight of dry screenings removed varies considerably (Table 89, Fig. 22).

**TABLE 89**

REMOVAL OF DRY SCREENINGS BY TWO-HOUR PERIODS

| Time | Lb. Dry Screenings per Mil. Gal. | | | |
|---|---|---|---|---|
| | March 22 and 23 | March 24 and 25 | March 26 and 27 | Average |
| 7:30 a. m. to 9:30 a. m. | 422 | 541 | 338 | 434 |
| 9:30 a. m. to 11:30 a. m. | 530 | 540 | 533 | 534 |
| 11:30 a. m. to 1:30 p. m. | 526 | 400 | 388 | 438 |
| 1:30 p. m. to 3:30 p. m. | 582 | 571 | 648 | 600 |
| 3:30 p. m. to 5:30 p. m. | 582 | 691 | 783 | 685 |
| 5:30 p. m. to 7:30 p. m. | 714 | 887 | 320 | 640 |
| 7:30 p. m. to 9:30 p. m. | 122 | 162 | 191 | 158 |
| Average | 497 | 542 | 457 | 499 |

The rate of accumulation gradually increased up to the early evening hours, dropping abruptly between 7:30 and 9:30 P. M. The

effect of the cessation of work during the noon hour is indicated by the drop in the curve between 11:30 A. M. and 1:30 P. M. The higher rate of accumulation during the late afternoon was probably caused by the additional material flushed into the sewers during the cleaning up after the days work.

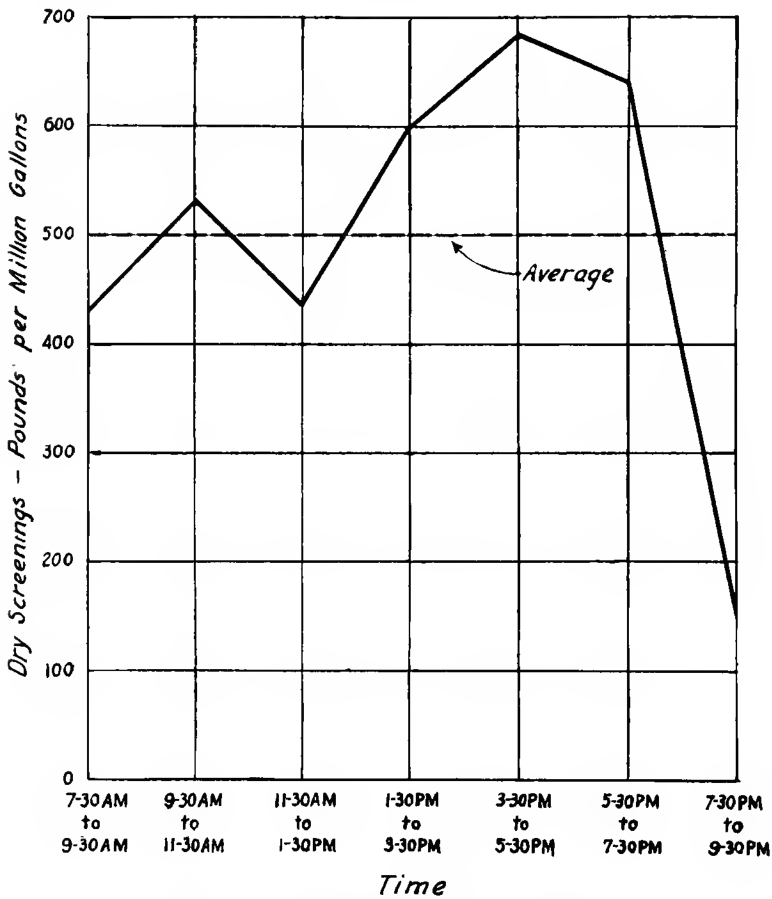


**Fig. 22. Variation in Removal of Screenings.**

REDUCTION IN BIOCHEMICAL OXYGEN DEMAND. A few comparative tests were made with the 30 mesh screen in 1915, to determine the reduction in biochemical oxygen demand by screening (Table 90).

These results confirm the results of previous tests, that little or no improvement in oxygen demand may be effected by fine screening.

**TABLE 90**

REDUCTION IN BIOCHEMICAL OXYGEN DEMAND BY FINE SCREENING

| Date 1915 | Biochemical Oxygen Demand Parts per Mil. | | Percent Reduction |
|---|---|---|---|
| | Influent | Effluent | |
| | 7:30 a. m. | to 9:30 p. m. | |
| March 22 and 23 | 970 | 870 | 10 |
| March 24 and 25 | 1000 | 900 | 10 |
| March 26 and 27 | 1020 | 1000 | 2 |
| Average | 1000 | 920 | 8 |
| | 7:30 a. m. | to 7:30 p. m. | |
| March 29 and 30 | 990 | 1010 | 2* |
| March 31 and April 1 | 1010 | 1050 | 4* |
| Adril 2 and 3 | 1120 | 1070 | 4 |
| April 5 and 6 | 960 | 910 | 5 |
| Average | 1020 | 1010 | 1 |

*Denotes Increase

SPECIAL TEST AT BOYD-LUNHAM COMPANY. A test was made on the screen at the Boyd-Lunham Co., during the week, December 24 to 31, 1917. The plant is located in Packingtown at 45th and Cook Sts., a typical packing concern of moderate size, slaughtering hogs. In addition to the various pork products, lard, inedible grease and fertilizer are made. About 300 people were employed at the plant. The capacity was about 350,000 hogs per annum, between 1,000 and 2,000 being slaughtered daily. In summer all slaughtering was done during the forenoon.

The wastes from the plant, containing no human sewage, passed through a catch basin 3 ft. wide by 7 ft. deep by 32 ft. long, before being screened. The basin was skimmed for grease. A by-pass was provided through which the sewage from the basin could flow direct to the main sewer, when the screen was out of order.

The Green Bay Foundry and Machine Works, Green Bay, Wis., made the screen, which was 5 ft. in diameter by 6 ft. long, covered with a 40 mesh brass screen built in panels. The sewage entered at one end, the other end being sealed. Screenings were conveyed to the open end by a screw conveyor. The screen was cleaned by jets of air and steam.

The flow through the screen was measured by means of a rectangular weir with an 8 inch crest, with end contractions, placed in the catch basin. Weir readings and samples of the influent and effluent were taken every 15 minutes from 7 A. M. to 7 P. M. Composite samples of influent and effluent were made for periods of 2 hours, a combined daily composite sample of each being made according the flow.

## TABLE 91

SCREEN TEST AT BOYD-LUNHAM CO. 40 MESH

Recovery of Solids and Reduction in Suspended Matter

| Date 1917 | Total Flow Thru Screen Gal. | Screenings | | | Total Suspended Matter | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Total Wet Lb. Recovered | Percent Moisture | Total Equiv. Dry Lb. | Influent* Calc. P.P.M. | Effluent P.P.M. | Difference P.P.M. | Percent Reduction | |
| Dec. 24 | 92,250 | 477 | 85.8 | 68 | 1104 | 1016 | 88 | 8.0 | 40 Mesh Screen |
| 26 | 136,100 | 1080 | 83.2 | 182 | 1072 | 912 | 160 | 14.9 | |
| 27 | 129,600 | 1154 | 87.7 | 142 | 839 | 708 | 131 | 15.6 | |
| 28 | 149,100 | 2398 | 83.2 | 403 | 1616 | 1292 | 324 | 20.0 | |
| 29 | 145,900 | 2826 | 84.0 | 452 | 1271 | 900 | 371 | 29.2 | |
| 31 | 113,490 | 1673 | 84.1 | 266 | 1611 | 1330 | 281 | 17.4 | |
| Total | 766,000 | 9608 | ...... | 1510 | ...... | ...... | ...... | ...... | |
| Average | ...... | ...... | 84.3 | ...... | 1262 | 1025 | 237 | 18.8 | |

*Influent Calculated from Effluent Analysis Plus Dry Screenings
NOTE:—Dry Screenings Recovered per Million Gallons Sewage Screened = 1970

In several instances, the screen became clogged, backing up the sewage into the catch basins. As soon as this occurred the attendant applied steam, as the air applied was not sufficient to keep the mesh clean. The use of a small spray of steam and water continuously would have helped. The screenings were collected and weighed in large flat wooden boxes. A composite sample of the screenings was made daily, on which moisture content was determined.

During the entire test, 766,000 gallons of sewage were screened, from which 9,608 lb. of wet screenings were actually recovered, equivalent to 1,510 lb. of dry screenings (Table 91). This is equivalent to a recovery of 1,970 dry lb. of screenings per mil. gal. of sewage screened, or a reduction of 18.8 per cent of the total suspended matter.

In Table 92 are shown the quantity of water used and weight of dry screenings recovered per hog killed. The results, though not very consistent, indicate the relation between animals slaughtered and wastes produced at this plant.

**TABLE 92**

SCREEN TEST AT BOYD-LUNHAM CO.

Relation Between Flow, Material Recovered and Hogs Killed

| Date 1917 | Number of Hogs Killed | Total Flow Thru Screen Gal. | Equiv. Dry Lb. of Screenings Recovered | Dry Lb. of Screenings Recovered per M. G. | Dry Lb. of Screenings Recovered per Hog | Gal. of Water Used per Hog |
|---|---|---|---|---|---|---|
| Dec. 24 | 881 | 92,250 | 68 | 738 | 0.84 | 1050 |
| 26 | 1069 | 136,100 | 182 | 1340 | 1.25 | 1270 |
| 27 | 1078 | 129,600 | 142 | 1097 | 1.02 | 1200 |
| 28 | 1484 | 149,100 | 403 | 2700 | 1.82 | 1010 |
| 29 | 1904 | 145,900 | 452 | 3100 | 1.63 | 770 |
| 31 | 952 | 113,490 | 266 | 2345 | 2.46 | 1200 |

Analyses of the dry screenings (Table 93) are remarkable for the high content of organic nitrogen and of ether soluble matter. The screenings are put in the rendering vats with tankage and cooked for grease recovery. The material is then pressed in a hydraulic press and dried in a steam jacketed dryer.

This test with a 40 mesh screen, showed a per cent removal of suspended solids approximately the same as that obtained with a 30 mesh screen at the testing station. The screenings contained more moisture than those removed at the testing station, but were much higher in nitrogen and fats.

## TABLE 93

ANALYSES OF SCREENINGS FROM 40-MESH SCREEN OF BOYD-LUNHAM CO.

Percent Calculated on Dry Basis

| Date 1917 | Volatile Matter | Fixed Matter | Organic Nitrogen | Ether Soluble | | | |
|---|---|---|---|---|---|---|---|
| | | | | Ethyl Ether | | Petroleum Ether | |
| | | | | Non-Acid | Acid | Non-Acid | Acid |
| July 7 to 16 | 93.5 | 6.5 | 4.00 | 22.62 | 23.64 | .......... | .......... |
| Dec. 24 to 27 | 95.3 | 4.7 | 6.64 | 23.10 | 24.64 | 17.96 | 20.58 |
| Dec. 28 to 31 | 92.5 | 7.5 | 4.64 | 22.12 | 28.64 | 15.40 | 17.77 |

The average weight of hogs in the Chicago market in December, 1917, was 211 lb. From the data in Table 92, the amount of screenings caught per hog ranged roughly from 0.4 to 1.26 per cent of the hogweight, averaging 0.71 per cent. As the average removal of screenings was 18.8 per cent of the suspended matter, the loss in suspended matter per hog would average 3.17 per cent of the hogweight.

## CHAPTER XII.

## ACID TREATMENT.

GENERAL. Two series of experiments on acidification of Packingtown sewage were run,—the first from August 24 to November 6, 1914, and the second from May 13 to July 10, 1915. Both were made in Dortmund tank (tank C), 7 ft. 8 in. diameter with a total water depth of 9 ft. 1½ in. Sewage entered at the center at a depth of 4 ft. 8 in. and the effluent was removed by a peripheral pipe ring with 16 upstanding 1½ in. pipe nipples equally spaced. The bottom was shaped in a cone with a slope of 60 degrees with the horizontal. All experiments were run with sulphuric acid, 66 deg. Be., diluted sufficiently with water to permit reasonable accuracy of control. The acid solution was mixed in barrels and applied to the sewage in the influent trough to the tank through a glass stop-cock with constant head overflow. The rate of flow through the glass stop-cock was frequently checked during the day by measuring the discharge of acid solution and timing with a stop watch, and the necessary adjustments made to keep the rate of application as constant as possible. With the crude method of control used, some unavoidable variation occurred from day to day. The sewage travelled about 10 feet through the trough after admission of the acid before entering the tank. Occasional samples taken during the first few days of the second series showed the tank effluent to be generally distinctly acid, although now and then an alkaline sample occurred. Acid was applied between the hours of 8 A. M. and 11 P. M. during the first series and between 8 A. M. and 10 P. M. during the second. These periods correspond with the sampling period for the crude day sewage. No acid was applied on Sundays. The results, therefore, are a composite of acidification for a portion of the time and plain sedimentation for the remainder. The operating schedule for the various runs is shown in Table 94. Sundays and other days, when no acid was applied, are included in the total hours of duration of test and total volume of sewage passed through the tank. The average number of hours per day when acid was applied includes only the days when acid was being used, while the rate of application of acid refers only to the volume of sewage actually acidified.

## TABLE 94

ACID TREATMENT—OPERATING DATA

| Run No. | Date Inclusive 1914-15 | Duration of Test | | | | Detention Period Hours | Sewage Treated—Gallons | | | Acid Applied (100%) | | Crude Sewage Alkalinity P.P.M. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days | Hours | | Avg. Hrs. Day Acid Appld. | | Total | With Acid | Percent Acidified | Lbs. per Million Gals. | Parts per Million | |
| | | | Total | Acid Applied | | | | | | | | |
| 1 | Aug. 24 to Sept. 14 | 22 | 511.0 | 252.0 | 14.0 | 2.9 | 255,000 | 125,800 | 49.3 | 3700 | 444 | 279 |
| 2 | Sept. 16 to Nov. 6 | 52 | 1206.0 | 617.0 | 14.7 | 4.0 | 447,200 | 229,000 | 51.1 | 3350 | 403 | 282 |
| 3 | May 13 to June 22 | 40 | 958.5 | 488.3 | 14.4 | 2.9 | 479,200 | 244,200 | 51.1 | 2950 | 354 | ...... |
| 4 | June 23 to July 10 | 18 | 432.0 | 224.0 | 14.0 | 2.0 | 324,000 | 168,100 | 51.9 | 2350 | 282 | ...... |

NOTE:—During ruo No. 2 no acid was applied from Oct. 17 to 20 inclusive

# TABLE 95

ACID TREATMENT. ANALYTICAL DATA

Removal of Various Constituents. Day Sewage

| Run No. | Detention Period Hours | Parts per Million: Nitrogen as Org. N | Free Amm. | Nitrites | Nitrates | Oxy. Cons. | Alkalinity as $CaCO_3$ | Biologic Oxygen Demand | Ether Soluble | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| INFLUENT | | | | | | | | | | |
| 1 | 2.9 | 60 | 20 | 0.37 | 2.36 | 171 | 279 | 960 | 135 | |
| 2 | 4.0 | 64* | 17* | 0.20* | 2.54* | 158* | 282* | 1000 | 120 | *10 days only |
| 3 | 2.9 | .... | .... | ........ | ........ | 158 | ...... | 960 | 157* | *Approximate |
| 4 | 2.0 | .... | .... | ........ | ........ | 165 | ...... | 1120 | 138* | *Approximate |
| EFFLUENT | | | | | | | | | | |
| 1 | 2.9 | 41 | 20 | 0.10 | 2.08 | 121 | —30 | 300 | 42 | |
| 2 | 4.0 | 41* | 19* | 0.00* | 1.98* | 120* | —96* | 260 | 40 | *10 days only |
| 3 | 2.9 | .... | .... | ........ | ........ | 121 | 0 | 520 | 92* | *Approximate |
| 4 | 2.0 | .... | .... | ........ | .... .... | 120 | +2 | 680 | 95* | *Approximate |
| PERCENT REMOVAL | | | | | | | | | | |
| 1 | 2.9 | 32 | 0 | 73 | 12 | 29 | ...... | 69 | 69 | |
| 2 | 4.0 | 36 | +12 | 100 | 22 | 24 | ...... | 74 | 67 | |
| 3 | 2.9 | .... | .... | ........ | ........ | 23 | ...... | 46 | 41 | |
| 4 | 2.0 | .... | .... | ........ | ........ | 27 | ...... | 39 | 31 | |

ANALYTICAL RESULTS. Effluent samples taken at intervals of one hour were combined into day and night composites for two day periods, with proper allowance for the theoretical detention period in the tank. The average results on the day sewage for each run (excluding suspended matter) together with percentage removals of the various constituents are shown in Table 95. In the last two runs, acid was applied at a considerably lower rate than in Runs 1 and 2. A much smaller removal of ether soluble material resulted. During Runs 3 and 4, the average results show the tank effluent to be neutral or slightly alkaline. This indicates a lack of sufficient acid to insure distinct acidity at all times, although this may no doubt be partially due to incomplete displacement in the settling portion of the tank and the inclusion of some of the unacidified night sewage in the effluent.

SUSPENDED MATTER. The average removal of suspended matter is shown in Table 96 for individual runs for the acidified day sewage, the unacidified night sewage and the composite 24 hour flow. During Runs 1 and 2, when an excess of acid was used, an average removal approximating 70 per cent was obtained on the day flow with theoretical detention periods of 3 and 4 hours. In Runs 3 and 4, where insufficient acid was used a distinct falling off in the efficiency of removal is to be noted, the results being no better than those obtained with plain sedimentation. Removal of suspended matter on Run 3, during a special series of hourly tests for determination of the reduction in biologic oxygen demand (Table 97) averaged about 70 per cent as against the 57 per cent appearing in Table 95. These hourly samples were taken during the middle of the day period, however, when the effluent was in general distinctly acid and are, therefore, better than the general average for the run as a whole.

OXYGEN REQUIREMENTS. In order to offset the sterilizing effect of the sulphuric acid, samples for the determination of the biologic oxygen demand were first neutralized with sodium bicarbonate and then seeded with sewage from the grit chamber. In the first 2 runs a few drops only were used, except for the last few days, when equal quantities of the neutralized acid effluent and the effluent from one of the plain sedimentation tanks were mixed and the demand for the acid effluent computed from the results obtained for the mixture and for the plain settled effluent. During Runs 3 and 4, 2 c. c. of grit chamber sewage were used to seed each sample. To test the efficiency of this method of in-

## TABLE 96

ACID TREATMENT. REMOVAL OF SUSPENDED MATTER

| Run No. | Detention Period Hours | Suspended Matter—Parts per Million | | | | | | Percent Reduction | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Influent | | | Effluent | | | | | | |
| | | Total | Vol. | Fixed | Total | Vol. | Fixed | Total | Vol. | Fixed | |
| DAY SEWAGE (Acidified) | | | | | | | | | | | |
| 1 | 2.9 | 380 | 301 | 79 | 111 | 94 | 17 | 71 | 69 | 79 | |
| 2 | 4.0 | 384 | 306* | 90* | 122 | 87* | 6* | 69 | 72 | 93 | *10 days only |
| 3 | 2.9 | 384 | 332* | 74* | 166 | 152* | 15* | 57 | 54 | 80 | *26 days only |
| 4 | 2.0 | 354 | 292 | 62 | 194 | 178 | 16 | 45 | 39 | 74 | |
| NIGHT SEWAGE | | | | | | | | | | | |
| 1 | 2.9 | 108 | ------ | ---- | 63 | ------ | ---- | 42 | ---- | ---- | |
| 2 | 4.0 | 110 | ------ | ---- | 72 | ------ | ---- | 35 | ---- | ---- | |
| 3 | 2.9 | 102 | ------ | ---- | 82 | ------ | ---- | 19 | ---- | ---- | |
| 4 | 2.0 | 99 | ------ | ---- | 71 | ------ | ---- | 28 | ---- | ---- | |
| 24-HOUR SEWAGE | | | | | | | | | | | |
| 1 | 2.9 | 276 | ------ | ---- | 93 | ------ | ---- | 66 | ---- | ---- | |
| 2 | 4.0 | 281 | ------ | ---- | 102 | ------ | ---- | 64 | ---- | ---- | |
| 3 | 2.9 | 266 | ------ | ---- | 131 | ------ | ---- | 51 | ---- | ---- | |
| 4 | 2.0 | 248 | ------ | ---- | 143 | ------ | ---- | 42 | ---- | ---- | |

NOTE:—Sunday Samples Omitted

## TABLE 97

ACID TREATMENT. REDUCTION OF SUSPENDED MATTER AND BIOLOGIC OXYGEN DEMAND

Individual Tests—Run No. 3

| Date 1915 | Turbidity | | Parts per Million | | | | | | | Percent Reduction | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Influent | | | Effluent | | | | Total Suspended Matter | Biological Oxygen Demand | |
| | Influent | Effluent | Total Suspended Matter | Bio. Oxy. Demand, Dilution Method | Bio. Oxy. Demand, Saltpeter Method | Total Suspended Matter | Bio. Oxy. Demand, Dilution Method | Bio. Oxy. Demand, Saltpeter Method | Alkalinity as $CaCO_3$ | | Dilution Method | Saltpeter Method |
| May 19 | ††† | †† | 432 | 1200 | 1030 | 164 | 550 | 630 | ...... | 62 | 54 | 38 |
| 19 | ††† | †† | 442 | 1130 | 1000 | 192 | 580 | 590 | ...... | 57 | 49 | 41 |
| 24 | ††† | †† | 526 | ...... | 820 | 98 | ...... | 210 | -80 | 82 | .... | 74 |
| 24 | ††† | †† | 396 | ...... | 770 | 52 | ...... | 450 | -82 | 87 | .... | 41 |
| 25 | ††† | † | 296 | ...... | 850 | 96 | ...... | 510 | -75 | 67 | .... | 40 |
| 25 | ††† | † | 384 | 880 | 740 | 60 | 560 | 490 | -83 | 84 | 37 | 34 |
| 25 | ††† | † | 376 | ...... | 770 | 46 | ...... | 380 | -98 | 88 | .... | 50 |
| 25 | ††† | † | 372 | ...... | 670 | 108 | ...... | 370 | -116 | 71 | .... | 44 |
| 25 | ††† | † | 732 | 1010 | 690 | 100 | 500 | 380 | -97 | 86 | 50 | 45 |
| 26 | ††† | † | 480 | 1000 | 940 | 150 | 560 | 550 | -25 | 69 | 44 | 41 |
| 26 | ††† | † | 480 | 980 | 1000 | 140 | 740 | 610 | -60 | 71 | 24 | 39 |
| 26 | ††† | † | 360 | 1050 | ...... | 112 | 640 | ...... | -112 | 69 | 39 | .... |
| 26 | ††† | † | 224 | ...... | 720 | 170 | ...... | 600 | -84 | 24 | .... | 16 |
| 28 | ††† | † | 292 | ...... | 670 | 128 | ...... | 550 | 0 | 56 | .... | 17 |
| 28 | ††† | † | 316 | 680 | 770 | 208 | 480 | 600 | -10 | 34 | 29 | 22 |
| 28 | ††† | † | 352 | 620 | 670 | 130 | 380 | 480 | -125 | 63 | 38 | 28 |
| June 1 | ††† | † | 698 | ...... | 1120 | 160 | ...... | 640 | +43 | 77 | .... | 43 |
| 1 | ††† | † | 408 | ...... | 1140 | 86 | ...... | 760 | +25 | 79 | .... | 33 |
| 2 | ††† | †† | 384 | ...... | 810 | 134 | ...... | 610 | -2 | 65 | .... | 24 |
| 3 | ††† | †† | 492 | 780 | 990 | 142 | 420 | 700 | -225 | 71 | 46 | 29 |
| 3 | ††† | †† | 468 | 640 | 960 | 160 | 400 | 720 | -208 | 66 | 36 | 25 |
| 4 | ††† | †† | 564 | 630 | 1000 | 116 | 380 | 650 | +3 | 79 | 40 | 35 |
| 4 | ††† | †† | 576 | ...... | 1070 | 140 | ...... | 650 | -3 | 76 | .... | 39 |
| 8 | ††† | †† | 478 | ...... | 1010 | 118 | ...... | 680 | -5 | 75 | .... | 32 |
| 8 | ††† | †† | 520 | 700 | 1040 | 90 | 470 | 600 | -102 | 83 | 33 | 43 |
| 9 | ††† | †† | 352 | ...... | 980 | 196 | ...... | 640 | -218 | 44 | .... | 35 |
| 11 | ††† | †† | 656 | ...... | 1190 | 164 | ...... | 640 | +10 | 75 | .... | 46 |
| 11 | ††† | †† | 500 | ...... | 850 | 190 | ...... | 660 | -86 | 62 | .... | 23 |
| 14 | ††† | †† | 392 | 460 | 850 | 114 | 270 | 640 | -40 | 71 | 41 | 25 |
| 14 | ††† | †† | 420 | ...... | 1020 | 136 | ...... | 580 | -30 | 68 | .... | 43 |
| 15 | ††† | †† | 464 | ...... | 920 | 214 | ...... | 390 | +50 | 54 | .... | 58 |
| 21 | ††† | †† | 184 | ...... | 890 | 56 | ...... | 460 | -58 | 70 | .... | 49 |
| 21 | ††† | †† | 276 | 420 | 1000 | 62 | 300 | 530 | -67 | 78 | 28 | 47 |
| 22 | ††† | † | 236 | ...... | 970 | 98 | ...... | 520 | +44 | 59 | .... | 46 |
| 22 | ††† | † | 324 | ...... | 800 | 80 | ...... | 510 | +65 | 75 | .... | 36 |
| Average All Results | | | 424 | 810 | 900 | 126 | 480 | 560 | -51 | 70 | 41 | 38 |
| Average Comparable Results | | | 452 | 800 | 910 | 130 | 470 | 580 | -87 | 71 | 41 | 36 |
| Average Acid Effluent | | | 410 | 820 | 870 | 125 | 490 | 550 | -75 | 70 | 40 | 37 |
| Average Alkaline Effluent | | | 479 | 630 | 1020 | 131 | 380 | 590 | +34 | 72 | 40 | 42 |

NOTE:— ††† Indicates Considerable Colloidal Matter; †† Decided Colloidal Matter ; and † Little Colloidal Matter

oculating the sample, a few bacterial counts on gelatin at 20 deg. C. were made before and after incubation. The initial counts varied from 40,000 to 114,000 per c. c. while the counts after incubation ranged from 6,000,000 to 18,000,000.

By far the greater part of the oxygen demand tests were made by the saltpetre method, but in the special series of hourly tests made during Run 3, some special dilution experiments were made for comparative purposes (Table 97). The percentage improvement in the character of the effluent was substantially the same by each method although the average oxygen demand shown by the dilution method was somewhat lower than with the saltpetre method on both the influent and effluent.

SLUDGE ACCUMULATION, ANALYSES AND DRYING. One noteworthy feature of this method of treatment was the relative slowness with which scum formed upon the surface of the tanks, whereas with plain settling in tanks of the Dortmund type, a heavy scum invariably appeared within a few days after cleaning, especially in warm weather. With acid treatment, this accumulation was delayed for two weeks or more and even then was

**TABLE 98**

ACID TREATMENT. SLUDGE AND SCUM ACCUMULATION

| Run No. | Detention Period Hours | Cubic Yards per Million Gallons | | |
|---|---|---|---|---|
| | | Sludge | Scum | Total |
| 1 | 2.9 | 5.9 | 2.1 | 8.0 |
| 2 | 4.0 | 8.8 | 0.0 | 8.8 |
| 3 | 2.9 | 5.6 | 0.7 | 6.3 |

**TABLE 99**

ACID TREATMENT. SLUDGE AND SCUM ANALYSES

| Date 1914-15 | Spec. Grav. | Percent Moisture | Percent—Dry Weight | | | | |
|---|---|---|---|---|---|---|---|
| | | | Nit. | Vol. | Fixed | Ether Soluble Without Acid | Ether Soluble With Acid |
| Top Scum | | | | | | | |
| June 15 | 1.00 | 86.8 | 3.36 | 81 | 19 | 17.7 | 32.2 |
| July 19 | 0.99 | 84.8 | 3.52 | 78 | 22 | 17.4 | 23.4 |
| Bottom Sludge | | | | | | | |
| Sept. 15 | 1.02 | 91.0 | 3.12 | 70 | 30 | 23.3 | ....... |
| Oct. 27 | 1.02 | 92.3 | 3.04 | 78 | 22 | 19.9 | ....... |
| Nov. 5 | 1.01 | 90.1 | 3.44 | 79 | 21 | 19.2 | ....... |
| June 15 | 1.02 | 92.8 | 2.72 | 79 | 21 | 18.7 | 29.0 |
| July 12 | 1.01 | 96.2 | 3.04 | 67 | 33 | 13.1 | 26.7 |

small in amount. Table 98 gives the average rate of sludge and scum accumulation during the various runs.

Analyses of both the bottom sludge and top scum are given in Table 99.

Notwithstanding the acid added to the sewage, results on ether extraction of acidified and unacidified samples during Runs 3 and 4 showed a large increase in the ether soluble matter of the former. This was probably due to the deposit of some sludge during the night and on Sundays when no acid was being applied and also because during the last two runs acid was not applied during the daytime in amounts sufficient to insure decided acidity at all times.

Several drying experiments were conducted on sand beds underlaid with gravel and provided with underdrains. The total thickness of filtering material was about 6 inches. The sludge, as drawn from the tanks, was rather thin, of a dirty greenish yellow color, and of very foul odor. In general the sludge dried somewhat less rapidly than the sludge from the Imhoff tank, evaporation of the water rising to the surface apparently playing an important part in the process. Results of drying experiments are shown on Table 100.

**TABLE 100**

ACID TREATMENT. SLUDGE DRYING EXPERIMENTS

| Run on Bed | | | Removed | | | | Remarks |
|---|---|---|---|---|---|---|---|
| Date 1914-15 | Depth on Bed Ft. | Percent Moisture | Days Elapsed | Depth on Bed Ft. | Percent Moisture | Percent Reduction Volume | |
| Sept. 15 | 0.80 | 97.1 | 7 | 0.22 | 72.5 | 72 | Sludge |
| Sept. 15 | 0.49 | 84.3 | 7 | 0.33 | 75.4 | 25 | Scum |
| June 15 | 1.02 | 94.5 | 21 | 0.37 | 75.0 | 64 | Sludge |

CONCLUSIONS. The experiments indicate that where sufficient acid is applied to provide a considerable excess acidity at all times, a somewhat better removal of suspended matter is obtained than with plain sedimentation under similar conditions. The difference is slight, however.

Considerable difference is noticeable in the reduction of the biologic oxygen demand between the first two and last two runs. Whether the difference is entirely due to a more complete removal of the oxidizable constituents in the first two runs with the higher rate of application of acid, or whether it is partially due to defects in method and manipulation with consequent retardation in the bacterial activity is not entirely certain. In the special tests made

during Run 3 considerably lower results were obtained both by the dilution and saltpetre methods when the samples were distinctly acid.

From the operating standpoint, the noteworthy feature is the extreme slowness of scum accumulation, as compared with the other sedimentation processes, on this sewage.

To insure successful operation, it is apparently necessary to have the sewage distinctly acid at all times. With the high alkalinity of the Packingtown sewage, the addition of sulphuric acid at the rate of from 350 to 400 p.p.m. would probably be necessary to attain this result. On the weaker night sewage the acidification might be reduced or even entirely omitted, although this would probably be undesirable. Using 400 p.p.m., the application of 100 per cent acid would be at the rate of about 3300 lb. per mil. gal. or if commercial 60 deg. Be. acid is used, about 4200 lbs. per mil. gal. If sulphur dioxide gas be used in accordance with the experiments at New Haven, about 2150 lb. per mil. gal. would be required. The use of sulphuric acid, or its equivalent in sulphur dioxide, would add considerably to the cost of operation.

Inasmuch as the experiments indicate comparatively slight improvement in the character of the effluent over that obtained with plain sedimentation, this process does not seem to be desirable for handling these wastes unless a considerable revenue can be derived by recovery of valuable by-products, principally grease. This point can only be determined after much more exhaustive investigation on a much larger scale than has here been attempted.

## APPENDIX 1.

## TESTS AT SMALLER PACKING HOUSES.
## 1915.

Individual tests at practically all packing houses in Packingtown were made during the spring and summer of 1911. Supplementary tests covering the new firms and some of the industries allied to the packing industry were made in 1915. The list of plants tested is given below:—

| Name of Plant | Location | Nature of Business |
|---|---|---|
| John Agar Company | 4057 S. Union Ave. | Packers |
| Guggenheim Brothers | 46th St. and Packers Ave. | Packers |
| A. Stecher | 47th St. and Racine Ave. | Casing Cleaners |
| Bechstein & Company | 45th Place and Packers Ave. | Casing Cleaners |
| Julius Bobsin | 923 W. 47th St. | Casing Cleaners |
| J. J. Cullinan | Racine Ave. near 47th St. | Gut String Mfrs. |
| American Gut String Co. | 4151 S. Ashland Ave. | Gut String Mfrs. |
| J. R. Beiersdorf Co. | 932 W. 38th Place | Pork Specialties |
| Jas. Hedges Co. | 4715 Bishop St. | Bladder Packers |
| Umbach Rendering Co. | 1615 W. 42nd St. | Rendering |

MEASUREMENT AND SAMPLING OF WASTES. At only two of the plants, the Agar Company and Guggenheim Brothers, was the flow sufficiently large to warrant the installation of weirs. At the other plants, meter readings were taken of the flow of water.

Samples and readings were taken every 10 minutes. The individual samples were combined into 2-hour composites for determinations of suspended matter and biochemical oxygen demand. Composites covering a day were made up from the bi-hourly samples in proportion to flow, and complete analyses made of these samples.

The complete analyses are given in Table 101. Bi-hourly analyses and flows are given in Tables 102 to 105.

## PACKINGHOUSES.

The John Agar Company and Guggenheim Brothers employ similar methods of operation. The weekly kill and the kill on the days on which samples were taken are given below:—

OPERATION. Pen and paunch manure are shipped away. Offal and scrap are rendered, Agar producing edible fats, Guggen-

## TABLE 101

ANALYSES OF SEWAGE FROM SMALL PACKINGHOUSES AND ALLIED INDUSTRIES

| Date 1915 | Parts per Million | | | | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nitrogen as | | | | Oxygen Cons. | Chlorine | Suspended Matter | | | Alkalinity in terms of Ca $CO_3$ | Total Solids | Fats | Biochemical Oxygen Demand | |
| | Total Organic | Free Amm. | Nitrites | Nitrates | | | Total | Volatile | Fixed | | | | | |
| A. Stecher | | | | | | | | | | | | | | |
| Mar. 11 | 332 | 54 | Tr. | 2.07 | 476 | 6500 | 472 | 412 | 60 | 600 | ... | ... | Over 2000 | |
| Bechstein & Co. | | | | | | | | | | | | | | |
| Mar. 17 | 355 | 185 | ... | ... | 664 | 4600 | 1890 | 1500 | 390 | 1000 | ... | ... | 3160 | |
| J. R. Beiersdorf & Bro. | | | | | | | | | | | | | | |
| Mar. 18 | 47 | 23 | ... | ... | 87 | 1600 | 304 | 222 | 82 | 850 | ... | ... | 730 | |
| Jas. Hedges Co. | | | | | | | | | | | | | | |
| Mar. 19 | ... | ... | ... | ... | ... | 448 | 408 | 40 | ... | ... | ... | ... | 6340 | Regular Waste |
| Mar. 19 | ... | ... | ... | ... | ... | 760 | 676 | 84 | ... | ... | ... | ... | 8500 | Floor Wash |
| Guggenheim Bros. | | | | | | | | | | | | | | |
| April 14 | 280 | 160 | ... | ... | 626 | 1050 | 824 | 784 | 40 | 980 | ... | 170 | 4860 | |
| April 15 | 520 | 160 | ... | ... | 669 | 1500 | 872 | 828 | 44 | 1200 | ... | 250 | 6190 | |
| Umbach Rendering Co. | | | | | | | | | | | | | | |
| April 20 | 8870 | 732 | ... | ... | 9810 | 2000 | 11,700 | 11,460 | 240 | 2800 | 114,800 | *10,400 | 4100 | *15,100 by Soxhlet |
| June 9 | 8334 | 466 | ... | ... | 6010 | 2000 | 860 | 808 | 52 | 2500 | ... | 912 | 9910 | |
| J. J. Cullinan | | | | | | | | | | | | | | |
| May 24 | 289 | 95 | ... | ... | 450 | 1300 | 1040 | 920 | 120 | 660 | ... | 181 | 2770 | |
| John Agar Co. | | | | | | | | | | | | | | |
| June 2 | 114 | 46 | ... | ... | 434 | 580 | 612 | 566 | 46 | 350 | ... | 251 | 1820 | 7 a.m. to 1 a.m. |
| Julius Bobsin | | | | | | | | | | | | | | |
| June 9 | 158 | 82 | ... | ... | 304 | 1800 | 851 | 833 | 18 | 660 | ... | 228 | 1970 | |
| American Gut String Mfg. Co. | | | | | | | | | | | | | | |
| July 23 | 215 | 57 | 0.24 | 2.16 | 444 | ... | 424 | 404 | 20 | 680 | ... | ... | ... | |

| Animals | John Agar Company | | | Guggenheim Brothers | | |
|---|---|---|---|---|---|---|
| | Weekly | June 2, '15 | June 3 | Weekly | April 14 | April 15 |
| Cattle | 500 | 148 | 163 | 800 | 198 | 196 |
| Calves | 50 | 5 | 0 | 30 | 6 | 14 |
| Sheep | 300 | 90 | 30 | 300 | 64 | 96 |
| Hogs | 1000 | 102 | 320 | 0 | 0 | 0 |

heim inedible. Blood is coagulated and mixed with the tankage for fertilizer. Agar evaporates the tankage liquor, Guggenheim does not. Casings and hides are sold green. No canning is done.

DISPOSAL OF WASTES. At the Agar plant, all tank liquids are said to be evaporated. The wash and floor water and the waste water from chilling the edible fats is passed through a concrete basin located outside the plant. This basin is 61 ft. 7 in. long by 6 ft. 0. in. wide inside, and the flow depth varies between 2.5 and 3 ft. It is divided into six compartments by transverse concrete baffles, five of which are between 10 and 13 feet apart, while the sixth is but 1 ft. 8 in. from the outlet end of the basin. The baffles are all underflow baffles with a clearance above the floor of about 10 in. The discharge is over a weir at the outlet end and thence to the sewer in Union Avenue. The outlet weir is provided with a gate through which the basin is drained for cleaning.

One 8-in. pipe enters the basin at the inlet end. A second inlet enters the second compartment. This brings the wastes from the killing floor, which contain a large amount of blood. These wastes first pass through a concrete basin 5 ft. 9 in. by 5 ft. 3 in. in plan, with a flow depth of about 7 ft., before entering the main basin. A third inlet enters the fourth compartment of the main basin.

The small basin receiving the wastes from the killing floor is cleaned about every two weeks, while the main basin is drained every Sunday and cleaned. It is skimmed daily for grease. The material removed from the basin is used as a filler for fertilizer. The drains from the cattle pens lead directly to the sewer without passing through the basin.

For the purpose of the tests, a 6-inch end-contracted weir was built at the end of the basin. Readings were taken at 10 minute intervals up to 7 P. M. on the first day and thereafter at

half hourly intervals. Between 1 A. M. and 7 A. M. there was no flow through the basin. At the Guggenheim plant, the wastes from the killing floor, cutting and shipping rooms, and the casing room are brought by two lines to a concrete basin located outside the plant. This basin is 37 ft. 4 in. long and 12 ft. wide inside. A tight, longitudinal baffle divides the basin into two equal parts, forcing the sewage to travel a distance of approximately 75 ft. before discharge. The flow depth is about 5 ft. 9 in. There are three transverse scum baffles, dipping about 8 in. below the surface. The basin is skimmed for grease and cleaned at weekly intervals, the material deposited being used for fertilizer.

The discharge from the tripe room formerly flowed directly to this basin but, owing to the superior quality of grease in this waste, a separate wooden basin has recently been put in operation. It is approximately 9 ft. long and 4 ft. wide, with a flow depth of about 3 ft. 8 in., with three transverse baffles, two of which are of the underflow type with a clearance of about 4 in., while the intermediate one is an overflow baffle. This basin discharges into the large concrete basin described above.

In the basement, there is a third basin which receives the waste liquor from the fertilizer press and from the rendering tanks. This basin is also skimmed for grease. It is 13 ft. long and 3 ft. 6 in. wide, with a flow depth of about 3 ft. Sewage enters at one end and discharges at the other, passing under three transverse underflow baffles with a clearance of about 6 in. at the bottom.

The effluent from both basins, together with drainage from the hide cellar, the cattle pens and the wastes from the engine room, discharge into a manhole south of the plant and flow to the sewer in 47th Street through an 18-in. pipe.

A 12-in. weir with two end-contractions was built in the last manhole and readings at half-hour intervals were taken during the two days covered by the tests. All waste discharge from the plant was included, with the exception of one of the drains from some of the pens. It was not possible to include this, but the flow was very small.

DISCHARGE AND ANALYSES OF WASTES. Average bi-hourly flows, together with determinations of suspended matter and biochemical oxygen demand, are given in Tables 102 and 103. Complete analyses are given in the summary (Table 101).

Wastes from both plants were of a deep brown color, very

turbid and high in suspended matter. Analyses of the Guggenheim wastes indicate that they are in general quite similar to those discharged from the packinghouses of the smaller type during the

## TABLE 102

GUGGENHEIM BROS.

DISCHARGE OF SEWAGE AND SUSPENDED MATTER AND BIOCHEMICAL OXYGEN DEMAND

Two Hour Composites

| Date April 1915 | Time | | Cu. Ft. per Sec. | | Parts per Million | |
|---|---|---|---|---|---|---|
| | From | To | Average | Maximum | Susp. Matter | Biochemical Oxy. Demand |
| 14 | 7:00 a. m. | 9:00 a. m. | 0.14 | 0.21 | 624 | 2400 |
| | 9:00 a. m. | 11:00 a. m. | 0.26 | 0.33 | 1430 | 6230 |
| | 11:00 a. m.<br>12:30 p. m. | 12:00 m.<br>1:30 p. m. | 0.21 | 0.27 | 340 | 3670 |
| | 12:00 m. | 12:30 p. m. | 0.10 | ....... | 760 | ....... |
| | 1:30 p. m. | 3:30 p. m. | 0.22 | 0.27 | 780 | 5670 |
| | 3:30 p. m. | 5:30 p. m. | 0.25 | 0.27 | 648 | 5340 |
| 15 | 7:00 a. m. | 9:00 a. m. | 0.20 | 0.24 | 1704 | 7210 |
| | 9:00 a. m. | 11:00 a. m. | 0.27 | 0.33 | 604 | 7170 |
| | 11:00 a. m.<br>12:30 p. m. | 12:00 m.<br>1:30 p. m. | 0.25 | 0.27 | 750 | 4590 |
| | 12:00 m. | 12:30 p. m. | 0.17 | ....... | 1248 | .... |
| | 1:30 p. m. | 3:30 p. m. | 0.24 | 0.27 | 504 | 6100 |
| | 3:30 p. m. | 5:30 p. m. | 0.18 | 0.25 | 624 | 5860 |
| Weighted Average*.......... | | | 0.22 | 0.33 | 805 | 5630 |

*Samples from 12:00 noon to 12:30 p. m. excluded

## TABLE 103

JOHN AGAR COMPANY

DISCHARGE, SUSPENDED MATTER AND BIOCHEMICAL OXYGEN DEMAND

Two Hour Composites

| Date 1915 June | Time | | Flow Cu. Ft. per Sec. | | Parts per Million | |
|---|---|---|---|---|---|---|
| | From | To | Average | Maximum | Susp. Matter | Biochemical Oxy. Demand |
| 2 | 7:00 a. m. | 9:00 a. m. | .06 | .16 | 508 | 2280 |
| | 9:00 a. m. | 11:00 a. m. | .19 | .26 | 460 | 2470 |
| | 11:00 a. m. | 1:00 p. m. | .18 | .24 | 252 | 1180 |
| | 1:00 p. m. | 3:00 p. m. | .32 | .47 | 180 | 1070 |
| | 3:00 p. m. | 5:00 p. m. | .32 | .39 | 324 | 1310 |
| | 5:00 p. m. | 7:00 p. m. | .23 | .39 | 268 | 1930 |
| | 7:00 p. m. | 9:00 p. m. | .05 | .12 | 364 | 1990 |
| | 9:00 p. m. | 11:00 p. m. | .12 | .20 | 256 | 1880 |
| | 11:00 p. m. | 1:00 a. m. | .12 | .20 | 4570 | 4470 |
| 3 | 1:00 a. m. | 3:00 a. m. | .00 | ....... | ....... | ....... |
| | 3:00 a. m. | 5:00 a. m. | .00 | ....... | ....... | ....... |
| | 5:00 a. m. | 7:00 a. m. | .00 | ....... | ....... | ....... |
| | 7:00 a. m. | 9:00 a. m. | .10 | .18 | 292 | 3330 |
| | 9:00 a. m. | 11:00 a. m. | .17 | .20 | 380 | 2210 |
| | 11:00 a. m. | 1:00 p. m. | .22 | .34 | 240 | 1630 |
| | 1:00 p. m. | 3:00 p. m. | .43 | .50 | 300 | 1890 |
| | 3:00 p. m. | 5:00 p. m. | .42 | .55 | 320 | 3340 |
| | 5:00 p. m. | 7:00 p. m. | .26 | .41 | 300 | 3150 |
| Weighted Average | 7:00 a. m. | 7:00 p. m. | .24 | .55 | 301 | 1960 |
| Max......... | 7:00 p. m. | 1:00 a. m. | .10 | .20 | 2060 | 2980 |

tests of 1911. The biochemical oxygen demand is from five to six times that of the Center Avenue sewage. The wastes from the Agar Company were comparatively weak, the strength being less than half that of the Guggenheim wastes.

CASING AND GUT STRING MANUFACTURERS. Tests were made at five small plants, specializing in the preparation of casings and gut strings, listed below.

| Firm | No. of Employees | Animals | No . per Week |
|---|---|---|---|
| A. Stecher | 40 | Sheep | 14,000 |
| Bechstein & Company | 75 | Sheep and Hogs | 60,000 |
| Julius Bobsin | .... | Hogs | 5,000 |
| J. J. Cullinan | 20 | Sheep | ---------- |
| American Gut String Co. | 15 | Sheep | ---------- |

OPERATION. The processes employed at these plants are similar. The minor differences found do not affect appreciably the character of the wastes discharged. The lower plants have machines for cleaning the green casings. Stecher has three, Bechstein five, Bobsin one. These machines consist essentially of a pair of cylindrical revolving rollers, set parallel to each other, with very slight clearance between. The casings pass between these rolls, and are thus drawn over a cylindrical drum against which a revolving knife lightly presses. This knife is provided with a number of blunt blades set radially, and as the casings pass underneath, the superfluous fat and tissue are scraped off and the slimy material inside is pressed forward and expelled from the end of the casing. To assist in cleaning, a spray of water from a perforated pipe is directed against the casings as they pass over the drum. A trough is attached to each machine in which the casings soak till they are ready to be cleaned. This trough is emptied daily. From the cleaning machines, the casings pass to the sorting room, where they are graded, according to size, on metal top tables by girls. The sizing is done by partially filling the casings with water, and noting the diameter of the swollen casing. Considerable water is used in this work, which escapes to the floor drains. It is, however, comparatively clear, as the casings have been thoroughly cleaned prior to grading.

After grading, sheep casings are measured, hog casings weighed. They are then salted by dragging across a bed of salt and are ready to be packed in barrels. Some salt, spilled upon the

floor, is washed to the gutters, although an effort is made to prevent waste. The casings to be used for the manufacture of gut strings are further cleaned by hand, soaked for several days in water, changed daily, and then bleached for about 5 hours in a solution of hydrogen peroxide. They are then rinsed, twisted and dried.

DISPOSAL OF WASTES. At all plants small boxes, approximately 3 ft. square, receive the wash water from the casing-cleaning machines. Small catch-basins are provided on the outlet drains in some plants, but in general these boxes and basins retain only the larger scraps and pieces of guts.

At the Stecher plant, the entire flow passes through two settling basins 1 ft. deep, one 3.5 by 12 ft. in plan, the other 3.5 by 10.0 ft., before discharge to a sewer in Racine Avenue. At the Bechstein plant, there are no settling basins, the wastes discharging directly into the 15-inch sewer in 45th Place leading to the Center Avenue sewer. The Bobsin plant waste discharges directly into the 47th Street sewer. Cullinan has a bar screen on the outlet gutter, with 1/8 in. bars, with a clear opening of about 1/2 in. The wastes discharge into the Center Avenue sewer. The wastes from the American Gut String Company flow direct to the Ashland Avenue sewer.

**TABLE 104**

DISCHARGE, SUSPENDED MATTER AND BIOCHEMICAL OXYGEN DEMAND

Two Hour Composites

| Time | | Flow C. F. P. S. | Parts per Million | | Remarks |
|---|---|---|---|---|---|
| From | To | | Susp. Matter | Biochemical Oxy. Demand | |
| A. STECHER COMPANY | | | | | |
| 7:00 a. m. | 9:00 a. m. | 0.053 | 540 | Over 2000 | |
| 9:00 a. m. | 11:00 a. m. | 0.071 | 410 | Over 2500 | |
| 11:00 a. m. / 12:30 p. m. | 12:00 Noon / 1:30 p. m. | 0.055 | 620 | 2160 | |
| 12:00 Noon | 12:30 p. m. | 0.006 | 236 | ........ | Noon Hour |
| 1:30 p. m. | 3:30 p. m. | 0.053 | 460 | 1890 | |
| 3:30 p. m. | 5:30 p. m. | 0.053 | 1090 | Over 2000 | |
| Weighted Average* | | 0.057 | 606 | ........ | |
| BECHSTEIN & COMPANY | | | | | |
| 7:00 a. m. | 9:00 a. m. | 0.131 | 2160 | 3850 | |
| 9:00 a. m. | 11:00 a. m. | 0.145 | 2100 | 3280 | |
| 11:00 a. m. / 12:30 p. m. | 12:00 Noon / 1:30 p. m. | 0.138 | 2490 | 3220 | |
| 12:00 Noon | 12:30 p. m. | 0.005 | 520 | ........ | Noon Hour |
| 1:30 p. m. | 3:30 p. m. | 0.138 | 1680 | 2880 | |
| 3:30 p. m. | 5:10 p. m. | 0.155 | 2470 | 4160 | |
| Weighted Average* | | 0.140 | 2160 | 3160 | |

*Samples from 12:00 noon to 12:30 p. m. excluded

## TABLE 105

JULIUS BOBSIN

DISCHARGE OF SEWAGE, SUSPENDED MATTER AND BIOCHEMICAL OXYGEN DEMAND

Two Hour Composites

| Time | | Flow C. F. P. S. | Parts per Million | |
|---|---|---|---|---|
| From | To | | Suspended Matter | Biochemical Oxy. Demand |
| 8:30 a. m. | 10:30 a. m. | .028 | 1940 | 3400 |
| 10:30 a. m. | 12:30 p. m. | .016 | 376 | 1450 |
| 12:30 p. m. | 3:30 p. m. | .022 | 150 | 1130 |
| 3:30 p. m. | 5:30 p. m. | .005 | 87 | 1130 |
| Weighted Average | | .018 | 800 | 1970 |

J. J. CULLINAN COMPANY

SUSPENDED MATTER AND BIOCHEMICAL OXYGEN DEMAND

| Time | | Parts per Million | |
|---|---|---|---|
| From | To | Suspended Matter | Biochemical Oxygen Demand |
| 7:00 a. m. | 9:00 a. m. | 1170 | 3890 |
| 9:00 a. m. | 11:00 a. m. | 1360 | 2520 |
| 11:00 a. m. | 1:00 p. m. | 1420 | 3050 |
| 1:00 p. m. | 3:00 p. m. | 1610 | 2430 |
| 3:00 p. m. | 5:00 p. m. | 540 | 1970 |
| Average | | 1220 | 2770 |

DISCHARGE AND ANALYSES OF WASTES. The bi-hourly results obtained at these five plants are given in Tables 104 and 105. Complete analyses of the wastes are given in the summary (Table 101). The flow at the American Gut String Company was not measured, being very intermittent, depending upon the use of the cleaning machine, which may be in operation several days a month. At most, the flow averaged less than 1000 gallons per day.

The wastes from these plants have a turbid, milky appearance, frequently containing pieces of gut of considerable size. The strength of all the samples is from two to three times greater than the Center Avenue sewage, but less than the wastes from the smaller packinghouses.

BEIERSDORF. The Beiersdorf plant prepares pork products, such as sausage, boiled ham, etc. The main source of waste is the discharge from the 10 cooking vats, each having a capacity of 3000 gal. The liquor from these vats is usually discharged daily and

passes through a skimming basin 15 ft. long by 3 ft. 9 in. wide, 3 ft. 6 in. deep. The flow through this basin is intermittent, depending upon the emptying of the cooking vats. The grease is skimmed off this basin daily and sold to soap makers. The sewage and wash water passes to a second basin 2 ft. 6 in. wide, 6 ft. long and 3 ft. 6 in. deep, the effluent from this basin being combined with that from the larger basin, discharging into a third basin about 5 ft. square and several feet deep before passing to the sewer.

No gagings were made at this plant. In February, 1915, about 300,000 gallons of sewage were discharged, or approximately 11,000 gal. per day. The waste collected was of a light straw color, low in suspended matter and with comparatively slight turbidity. The complete analysis is given in the summary (Table 101).

JAMES HEDGES. The Hedges plant handles about three million hog bladders per year. They are soaked in barrels for three days in salt brine, the strength of which is increased daily, in order to bleach them. They are then expanded with air. The waste tissue is trimmed off. The bladders are dried in a hot room and packed for shipment. Practically all operations are carried on with the use of little or no water. During February, 1915, the daily consumption of water averaged 4000 gal., but nearly all of this was used for boiler purposes. Less than a thousand gallons of waste are discharged daily. Partial analysis of the waste and floor washings are given in the summary (Table 101).

UMBACH RENDERING COMPANY. This company renders butchers' scraps for tallow, from four to six tanks being handled weekly. The scraps are cooked under steam pressure to liberate the grease, which rises to the top and is drawn off. The water from the tankage is then withdrawn at the bottom, and finally the solid residue is discharged and pressed for use in fertilizer. The waste water from the rendering tanks and the tankage press is led to a small skimming basin, approximately 15 ft. long by 3 ft. wide, with a flow depth of about 2 ft. 5 in. The total discharge per week is estimated at from 1,500 to 2,000 gallons.

One test was made on April 20, during the discharge of a tank, samples being collected at short intervals and averaged into a composite. Owing to the comparatively low biochemical oxygen demand as compared with the excessive organic nitrogen content, the test was repeated under the same conditions on June 9. The results of the two tests are shown in Table 101. The two tests

differ considerably, particularly as regards the amount of suspended matter and fat. Both of these constituents were abnormally high on the first test. The great difference may, perhaps be traced to varying care in drawing off the tank and in judging the dividing line between the tallow and waste liquor. Organic nitrogen, free ammonia and oxygen consumed in both tests were excessively high. The biochemical oxygen demand was also very high, the demand in the second test running over twice that in the first.

Cullinan's water meter being out of repair, no flow measurements were obtained. Between April 12 and May 2, 1915, a total of 173,000 gal. of water were used on an average of 1,000 gal. per day, excluding Sundays. Based on a 10 hour day, this makes an average rate of 0.038 cu. ft. per sec.

## SUMMARY OF TESTS.

The plants of the John Agar Company and Guggenheim Brothers are both typical packing houses of the smaller type. The wastes discharged are similar to those investigated in 1911, from a comparison of analyses. Additional information covering the biochemical oxygen demand of these wastes, not secured in 1911, was also obtained, the average for the day flow being about 1,800 and 5,600 p.p.m. respectively. This large variation is probably due to difference in method of operation. At the Agar plant, evaporation of the waste liquors is carried out more completely than at the plant of Guggenheim Bros.

The wastes from the three casing cleaning establishments tested were similar in character, all showing a turbid, milky appearance, being high in suspended matter and having a biochemical oxygen demand averaging about 2,500 p.p.m. The volume of wastes discharged from individual plants is so small as to make mechanical screening out of the question. Fine screens, hand-operated, possibly supplemented by small settling basins, would effect a considerable improvement in these wastes as they contain large quantities of comparatively coarse suspended organic matter.

The manufacture of gut strings involves essentially the same processes as are used in the cleaning of casings, and the wastes produced are quite similar although probably somewhat smaller in amount.

The wastes produced at the plant of J. R. Beiersdorf and Bro. are considerably weaker than the regular packinghouse wastes. The discharge although not measured is quite small. This plant is not directly tributary to Bubbly Creek, but ultimately discharges through the 35th St. sewer. The waste from the plants of Jas. Hedges and Umbach Rendering Company are very strong, but the volume discharged was extremely small.

The total volume of wastes represented in the tests listed above is approximately 0.7 c.f.p.s. or about 2 percent of the total day flow included in the 1911 tests.

## APPENDIX 2.

### TESTS ON INDIVIDUAL HOUSES AND MAIN SEWERS. 1917.

GENERAL. During the summer and fall of 1917, a series of gagings and analyses was made, similar to those made in 1911, but on a much more extensive scale, on the various individual outlets and main sewers in Packingtown. All outlets of any importance, including the outlying houses, were gaged and sampled and in practically all cases the tests on each outlet extended over an entire week. Except for the sewer discharging at Morgan St., the individual outlets in the stockyards proper were not included in this investigation, but, in October, 1919, a few gagings and analyses were made on some of these outlets, the results of which are included in this report. In addition to the gagings and analyses, a record of the kill during the tests was kept (Table 106). The results are summarized in the following tables (Tables 107 to 115), most of which are self-explanatory. From the results of these tests, Table 116 has been compiled to show the estimated proportional liability of each firm toward the cost of a common disposal plant. In computing this table, it has been assumed that 15 per cent of the cost of the plant—mainly the grit chamber, pumping equipment, fine screens, settling tanks and sewage channels, depends directly upon the volume of day flow; that 30 percent of the cost, mainly sludge concentration tanks and sludge handling equipment, depends upon the daily amount of suspended matter, and that the remaining 55 percent, principally the aeration tanks, air compressing and distributing equipment, depend upon both the day flow and day biologic oxygen demand, equal weight being given each factor. These various percentages were determined from a study of the detailed estimates for the total cost of a plant to handle the Packingtown situation as reported by Pearse and Richardson, April 16, 1917, and from these percentages and the figures for day flow, biologic oxygen demand and 24 hour suspended matter discharge for each firm, a properly weighted percentage liability was established for each. Inasmuch as no tests were made for the Union Stockyards and Transit Company except on the Morgan St. sewer, the results from this sewer draining about 27 acres were prorated over the entire area of the Yards (about 194 acres) and an estimate total was computed to cover this entire area.

# TABLE 106

PACKINGTOWN SEWER INVESTIGATIONS—1917

Record of Killing During Tests

| Firm | Outlet | Dates of Test (Inclusive) 1917 | Kill: Cattle | Kill: Calves | Kill: Hogs | Kill: Sheep | Kill: Total |
|---|---|---|---|---|---|---|---|
| Armour & Co. | 43rd and Racine | | | | | | |
| | 43rd Pl. and Racine | Aug. 20 to 25 | 10,966 | 2,181 | 109 | 12,080 | 25,336 |
| | 44th and Racine | | | | | | |
| Swift & Co. | ¶42nd and Racine | Aug. 20 to 25 | ... | ... | 6,600 | 13,218 | 19,818 |
| | ¶Exchange and Racine— | | | | | | |
| | 41st and Ashland | Aug. 27 to Sept. 2 | 6,726 | 776 | ... | ... | 7,502 |
| | Packers Ave. | | | | | | |
| | Wool House | Sept. 4 to 11 | 4,506 | 1,515 | ... | ... | 6,021 |
| | 42nd and Ashland | Sept. 13 to 20 | | | | | |
| Morris & Co. | Exchange and Racine | Aug. 27 to Sept. 2 | ... | ... | 2,690 | ... | 2,690 |
| | 44th and Ashland | Sept. 5 to 11 | 9,193x | 994x | ... | 8,098x | 18,285 |
| | 42nd and Ashland | Sept. 13 to 20 | | | | | |
| Wilson & Co. | Ashland Ave. | Sept. 20 to 27 | 8,731 | 1,375 | 5,797 | 7,884 | 23,787 |
| | S. Y. Interceptor | Sept. 27 to Oct. 3 | | | | | |
| Hammond & Co. | Racine Ave. | July 23 to 28 | 3,170 | 277 | 7,133 | 4,114 | 14,694 |
| Miller & Hart | Racine Ave. | July 23 to 28 | ... | ... | 2,946 | ... | 2,946 |
| Chicago Packing Co. | Ashland Ave. | July 16 to 21 | 290 | 82 | 144 | ... | 516 |
| Guggenheim Bros. | Racine Ave. | July 23 to 28 | 1,938 | 12 | ... | 72 | 2,022 |
| Western Packing Co. | River | Aug. 6 to 11 | 509 | 58 | 6,343 | 472 | 7,382 |
| Independent Packing Co. | Halsted St. | Aug. 6 to 11 | 749 | 16 | 4,782 | 18 | 5,565 |
| Louis Pfaelzer & Sons | Halsted St. | Aug. 6 to 11 | 737 | 104 | 213 | 364 | 1,418 |
| Boyd-Lunham Co. | Racine Ave. | Dec. 24 to 31 | ... | ... | 7,368 | ... | 7,368 |
| Roberts & Oake | Racine Ave. | July 12 to 18 | ... | ... | 3,292 | ... | 3,292 |
| John Agar & Co. | Halsted St. | Oct. 1 to 6 | 1,346 | ... | 1,202 | ... | 2,548 |
| Peerless Packing Co. | 39th St. | Oct. 1 to 6 | 1,085 | 461 | ... | ... | 1,546 |
| Brennan Packing Co. | 39th St. | Dec. 3 to 8 | ... | ... | 6,334 | ... | 6,334 |
| Siegel-Hechinger | 35th St. | Sept. 11 to 17 | 1,042 | 98 | ... | ... | 1,140 |
| B. Pfaelzer | Halsted St. | Aug. 7 to 11 | 9 | 24 | ... | ... | 33 |
| D. Levi | River | July 30 to Aug. 4 | 116 | 40 | ... | ... | 156 |
| Total | | | 51,113 | 8,013 | 54,953 | 46,320 | 160,399 |

¶ 1200 g. p. m. from east beef house normally draining into 42 St. outlet to Ashland Ave. pumped into this sewer during test from 8 a. m. to 8 p. m.
*x* Average of Kill for two weeks during which these sewers were tested.

## TABLE 110—Continued

PACKINGTOWN SEWER INVESTIGATIONS—191

Pounds per Day of Suspended Matter, Organic Nitrogen and Biologic Oxygen Dem

| Outlet | Time Day Samples | Pounds per 24 Hour | | | | | |
|---|---|---|---|---|---|---|---|
| | | Total Suspended Matter | | | Organic Nitrogen | | |
| | | Day | Night | 24 Hours | Day | Night | 24 Hou |
| | | Tributary to Ashland Ave. Sewage | | | | | |
| Chicago Packing Co. | 7 a.m. to 7 p.m. | 850 | 110 | 960 | 126 | 17 | 1 |
| Morris & Co., 44th St. | 7 a.m. to 8 p.m. | 10,600 | 2,250 | 12,850 | 863 | 261 | 1,1 |
| Morris & Co., 42nd St.* | 7 a.m. to 8 p.m. | 2,410 | 780 | 3,190 | 376 | 139 | 5 |
| Swift & Co. | 7 a.m. to 8 p.m. | 18,530 | 3,950 | 22,480 | 1,334 | 271 | 1,6 |
| Swift & Co., (Wool House) | 6 a.m. to 7 p.m. | 7,090 | 860 | 7,950 | 534 | 61 | 5 |
| Darling & Co. | 8 a.m. to 8 p.m. | 1,530 | 530 | 2,060 | 265 | 82 | 3 |
| Wilson & Co. | 7 a.m. to 8 p.m. | 6,930 | 1,210 | 8,140 | 901 | 184 | 1,0 |
| Swift & Co., 41st St. | 7 a.m. to 8 p.m. | 8,980 | 1,130 | 10,110 | 568 | 72 | 6 |
| Libby, McNeil & Libby* | 7 a.m. to 8 p.m. | 2,220 | 810 | 3,030 | 192 | 43 | 2 |
| American Gut String Co.* | 7 a.m. to 6 p.m. | 90 | ........ | 90 | 11 | ........ | |
| Wilson & Co. (To S. Y. Int.) | 7 a.m. to .7 p.m. | 1,100 | 870* | 1,970 | 125 | 153 | 2 |
| | | Tributary to 39th St. Conduit | | | | | |
| Brennan Packing Co. | 7 a.m. to 7 p.m. | 790 | ........ | 790 | 189 | ........ | 1 |
| Peerless Packing Co. (B) | 6 a.m. to 10 p.m. | 150 | ........ | 150 | 16 | ........ | |
| Peerless Packing Co. (A) | 6 a.m. to 10 p.m. | 850 | ........ | 850 | 190 | ........ | 1 |
| | | Tributary to 35th St. Sewr | | | | | |
| Siegel-Hechinger | 7 a.m. to 7 p.m. | 260 | ........ | 260 | 84 | ........ | |
| J. R. Beiersdorf* | 8 a.m. to 5 p.m. | 110 | ........ | 110 | 18 | ........ | |
| | | Tributary to River Direct | | | | | |
| Western Packing Co. | 7 a.m. to 7 p.m. | 490 | ........ | 490 | 78 | ........ | |
| Oppenheimer Casing Co.* | 7 a.m. to 5 p.m. | 810 | ........ | 810 | 233 | ........ | 2 |
| Anglo-American Prov. Co. | 8 a.m. to 7 p.m. | 700 | ........ | 700 | 55 | ........ | |
| D. Levi | 7 a.m. to 7 p.m. | 190 | ........ | 190 | 26 | ........ | |
| Friedman Mfg. Co. | 7 a.m. to 6 p.m. | 240 | ........ | 240 | 25 | ........ | |
| Swift & Co. | 7 a.m. to 7 p.m. | 3,650 | 710 | 4,360 | 197 | 51 | 2 |
| Grand Total | | 109,270 | 18,710 | 127,980 | 11,099 | 2,041 | 13,1 |

NOTE:—Where nothing is recorded at night, no measurements were taken and flow assumed 0.0

39th St. 35th St. River D Halsted Halsted Morgan Racine- Racine- Ashland | Grand T | Total, 3 | River D Halsted Halsted Morgan Racine / Ashland | Grand T | Percent

# TABLE 111

## PACKINGTOWN SEWER INVESTIGATIONS—1917

Comparative Discharge by Main Outlets for Industrial and Total Flow. Suspeoded Matter, Organic Nitrogen and Biologic Oxygen Demand

| Outlet Tributary To | No. | Pounos per 24 Hours: Total Suspenoed Matter | | | Organic Nitrogen | | | Biologic Oxygen Demand | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Day | Night | 24 Hours | Day | Night | 24 Hours | Day | Night | 24 Hours |
| Packinghouse and Stockyards Sewage Only | | | | | | | | | | |
| 39th St. Sewer | 1 | 1,790 | 0 | 1,790 | 395 | 0 | 395 | 4,140 | 0 | 4,140 |
| 35th St. Sewer | 2 | 370 | 0 | 370 | 102 | 0 | 102 | 1,580 | 0 | 1,580 |
| River Direct | 3 | 6,080 | 710 | 6,790 | 614 | 51 | 665 | 9,940 | 1,110 | 11,050 |
| Halsted St. 4 Ft., 0 In. | 4 | 2,620 | 0 | 2,620 | 503 | 0 | 503 | 8,050 | 0 | 8,050 |
| Halsted St., 7 Ft., 0 In. | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Morgan St. | 6 | 490 | 0 | 490 | 22 | 0 | 22 | 300 | 0 | 300 |
| Racine—Packinghouse | 7 | 38,080 | 5,500 | 43,580 | 4,190 | 707 | 4,897 | 74,770 | 17,420 | 92,190 |
| Racine—Stockyards | 7 | 3,030 | 0 | 3,030 | 136 | 0 | 136 | 1,860 | 0 | 1,860 |
| Ashland Ave. | 8 | 60,330 | 12,500 | 72,830 | 5,295 | 1,283 | 6,578 | 95,610 | 27,490 | 123,100 |
| Grand Total | | 112,790 | 18,710 | 131,500 | 11,257 | 2,041 | 13,298 | 196,250 | 46,020 | 242,270 |
| Total, 3 to 8, incl. | | 110,630 | 18,710 | 129,340 | 10,760 | 2,041 | 12,801 | 190,530 | 46,020 | 236,550 |
| Total Flow—Outfall Sewers | | | | | | | | | | |
| River Direct | 3 | 6,080 | 710 | 6,790 | 614 | 51 | 665 | 9,940 | 1,110 | 11,050 |
| Halsted St., 4 Ft., 0 In. | 4 | 5,210 | 740 | 5,950 | 660 | 139 | 799 | 10,010 | 3,130 | 13,140 |
| Halsted St., 7 Ft., 0 In. | 5 | 8,040 | 2,850 | 10,890 | 707 | 279 | 986 | 12,320 | 5,330 | 17,650 |
| Morgan St. | 6 | 490 | 0 | 490 | 22 | 0 | 22 | 300 | 0 | 300 |
| Racine Ave. | 7 | 45,350 | 9,140 | 54,490 | 4,670 | 1,090 | 5,760 | 70,240 | 15,790 | 86,030 |
| Ashland Ave. | 8 | 68,170 | 28,000 | 96,170 | 6,435 | 3,153 | 9,588 | 129,970 | 55,820 | 185,790 |
| Grand Total | | 133,340 | 41,440 | 174,780 | 13,108 | 4,712 | 17,820 | 232,780 | 81,180 | 313,960 |
| Percent Industrial is of Total | | 82.8 | 45.2 | 74.0 | 82.0 | 43.3 | 71.9 | 81.8 | 56.5 | 75.3 |

**TABLE 112**

PACKINGTOWN SEWER INVESTIGATIONS—1917

Comparative Summary—Flows from Individual Outlets—1911 and 1917

| Outlet | Tributary to Sewer | Flow—Cu. Ft. per Sec. | | | |
|---|---|---|---|---|---|
| | | Day | | 24-Hours | |
| | | 1911 8 a.m. to 8 p.m. | 1917 7 a.m. to 7 p.m. | 1911 | 1917 |
| John Agar Co. | Halsted St. | 0.24* | 0.62 | 0.16* | |
| Independent Packing Co. | Halsted St. | 0.38 | 0.86 | | |
| L. Pfaelzer & Sons | Halsted St. | 0.20 | 0.25 | | |
| B. Pfaelzer | Halsted St. | 0.04 | 0.03 | | |
| No. American Prov. Co. | Racine Ave. | ¶0.06* | 0.14 | | |
| J. J. Cullinan | Racine Ave. | 0.04 | 0.06 | | |
| Guggenheim Bros. | Racine Ave. | 0.22* | 0.43 | | |
| Adler & Oberndorf | Racine Ave. | 0.14 | 0.07 | | |
| Hammond & Co. | Racine Ave. | 1.26 | 2.38 | 0.94 | 1.53 |
| Miller & Hart | Racine Ave. | 0.20 | 0.21 | | |
| Roberts & Oake | Racine Ave. | | 0.12 | | |
| Bechstein & Co. | Racine Ave. | 0.14 | 0.22 | | |
| Boyd-Lunham | Racine Ave. | 0.67 | 0.43 | | |
| Northwestern Glue Co. | Racine Ave. | 0.18 | 0.09 | | |
| Armour & Co., 44th St. | Racine Ave. | 1.55 | 2.79 | 0.90 | 2.17 |
| Armour & Co., 43rd Pl. | Racine Ave. | 2.42 | 4.89 | 2.03 | 4.58 |
| Armour & Co., 43rd St. | Racine Ave. | 2.98 | 10.07 | 2.02 | 7.64 |
| Swift & Co., 42nd St. | Racine Ave. | 1.39 | 1.86 | | 1.45 |
| Swift & Co., Exchange Ave. | Racine Ave. | 1.87 | 3.09 | | 2.36 |
| Morris & Co., Exchange Ave. | Racine Ave. | 0.94 | 0.98 | 0.64 | 0.66 |
| Chicago Packing Co. | Ashland Ave. | 0.22 | 0.27 | | 0.22 |
| Morris & Co., 44th St. | Ashland Ave. | 0.71 | 4.31 | 0.48 | 3.72 |
| Morris & Co., 42nd St. | Ashland Ave. | 1.30 | 1.74 | 1.12 | 1.55 |
| Swift & Co., 42nd St. | Ashalnd Ave. | 2.96 | 6.76 | 1.84 | 5.25 |
| Swift & Co., Wool House | Ashland Ave. | 1.46 | 1.78 | | 1.06 |
| Darling & Co. | Ashland Ave. | 0.23 | 0.33 | | 0.34 |
| Wilson & Co. | Ashland Ave. | 3.94 | 4.77 | 3.63 | 3.49 |
| Swift & Co., 41st St. | Ashalnd Ave. | 3.73 | 3.53 | | 2.84 |
| Libby, McNeil & Libby | Ashland Ave. | 0.41 | 0.96 | | 1.07 |
| American Gut String Co. | Ashalnd Ave. | 0.02* | 0.20 | | |
| Brennan Packing Co. | 39th St. | 0.41 | 0.39 | | |
| Peerless Packing Co. | 39th St. | 0.03* | 0.33 | | |
| Siegel-Hechinger | 35th St. | 0.09 | 0.18 | | |
| J. R. Beiersdorf | 35th St. | | 0.03 | | |
| Western Packing Co. | River | 0.78x | 0.53z | | |
| Oppenheimer Casing Co. | River | | 0.32 | | |
| Anglo American Prov. Co. | River | 1.98 | 0.26 | 1.58 | |
| D. Levi | River | | 0.08 | | |
| Friedman Mfg. Co. | River | 0.13 | 0.12 | | |
| Swift & Co., Packers Ave. | River | 0.61 | 1.65 | | 1.25 |
| Wilson & Co., (To S. Y. Int.) | Interceptor | | 0.59 | | 0.67 |
| Total—Corresponding Outlets | | 33.93 | 57.66 | 13.60 | 30.59 |

*Measurements Made in 1915
¶A. Stecher Only in 1915
xTwo Outlets
zOne Outlet

GAGINGS. In practically all cases flow measurements were made with standard weirs erected at suitable locations in the various sewers, but at several plants, water meter readings were taken instead. Readings were taken at 10 minute intervals, except on the main outfall sewers, where they were recorded every half hour, and were continued throughout the entire 24 hours, except at some of the very small plants where there was no appreciable night flow. Individual readings were averaged over periods of 1 hour, and these in turn were summarized (Tables 112 and 113). The average day flow in all cases covers the period from 7 a. m. to 7 p. m. and the night flow from 7 p. m. to 7 a. m. In figuring the average flow over 25 hours, the night flow was assumed as

zero for outlets where no measurements were taken. In a few cases where the daytime measurements did not extend over a full 12 hour period, the flow during the missing hours was taken at zero to reduce all to a common basis. As a result of these assumptions the night and average 24 hour flows are probably slightly low, but the day flows, which are most important, are substantially correct. Besides other detailed summaries giving the results of these gagings, Table 112 presents the comparative results for the day flows on individual outlets in 1911 and 1917. This shows an increase in discharge of sewage in 1917 of about 70 percent over that found in 1911. Table 117 shows the relative day and 24 hour flows on the main sewer outlets as measured in 1911, 1915 and 1917. It is difficult to account for the marked diminution in flow in the two Halsted St. sewers in 1917.

ANALYSES. Individual samples, taken at 10 minute intervals, were combined into hourly composites and these in turn were combined in the laboratory into day and night composites, weighted according to the hourly variations in flow. Division between the day and night samples was made according to the appearance of the hourly composites, those of high suspended matter content being included in the day sample. The division between day and night samples does not always coincide therefore with the division of time made in the gagings which were uniformly taken from 7 a. m. to 7 p. m. and 7 p. m. to 7 a. m. for the day and night flows respectively. The various chemical determinations were made according to the procedure outlined in the third edition of the Standard Methods of the American Public Health Association. Biologic oxygen demand determinations were made according to the saltpetre method worked out in detail by Dr. Arthur Lederer, former chemist of the Sanitary District. Late in the year determination of the ether soluble content was made at a number of the larger outlets on both unacidified and acidified samples (Table 116). The latter showed much higher results in nearly every instance. The results for the night and 24 hour discharge of suspended matter, organic nitrogen, and biologic oxygen demand are probably slightly low, owing to the assumption of zero flow made in the case of the smaller houses. The total kill during the tests was approximately 160,000 animals. The figures indicate a total discharge into the sewers of about 5 lb. of suspended matter and 0.5 lb. of organic nitrogen and a biologic oxygen demand of about 9 lb. per animal slaughtered.

# TABLE 113

PACKINGTOWN SEWER INVESTIGATIONS—1917

Comparative Discharge by Main Outlets. Industrial Flow and Total Flow

| Outlet Tributary To | No. | Flow—Cu. Ft. per Sec. | | | | | Ratio Industrial to Total Day Flow | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Average Day 7 a.m. to 7 p.m. | Average Night 7 p.m. to 7 a.m. | Average 24 Hours | Max. Day 7 a.m. to 7 p.m. | Max. Reading | | |
| **Packinghouse and Stockyards Sewage Only** | | | | | | | | |
| 39th St. Conduit | 1 | 0.72 | 0.00 | 0.37 | 0.82 | 1.37 | .......... | |
| 35th St. Sewer | 2 | 0.21 | 0.00 | 0.10 | 0.27 | 0.55 | .......... | |
| River Direct | 3 | 2.96 | 0.85 | 1.90 | 4.00 | 5.20 | 100.0 | |
| Halsted, 4 Ft., 0 In. | 4 | 1.76 | 0.00 | 0.91 | 2.17 | 3.61 | 45.1 | |
| Halsted, 7 Ft., 0 In. | 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 | 10 days |
| Morgan St. | 6 | 1.10 | 0.00 | 0.60 | 1.20 | 2.40 | 100.0 | 5 days |
| Racine—Packinghouse | 7 | 27.83 | 14.91 | 21.30 | 31.48 | 43.18 | 93.0 | |
| Racine—Stockyards | 7 | 6.82* | 0.00* | 3.41* | 7.45* | 14.90* | 93.0 | *Estimated |
| Ashland Ave. | 8 | 25.24 | 15.23 | 20.21 | 27.65 | 34.07 | 58.7 | |
| Grand Total | .......... | 66.64 | 30.99 | 48.80 | 75.04 | 105.28 | .......... | |
| Total—3 to 8, incl. | .......... | 65.71 | 30.99 | 48.33 | 73.95 | 103.36 | .......... | |
| **Total Flow—Outfall Sewers** | | | | | | | | |
| River Direct | 3 | 3.0 | 0.9 | 1.9 | 4.0 | 5.2 | .......... | |
| Halsted St., 4 Ft., 0 In. | 4 | 3.9 | 3.7 | 3.8 | 4.5 | 5.7 | .......... | |
| Halsted St., 7 Ft., 0 In. | 5 | 21.9 | 21.3 | 21.6 | 24.3 | 29.6 | .......... | 10 days |
| Morgan St. | 6 | 1.1 | 0.0 | 0.6 | 1.2 | 2.4 | .......... | 5 days |
| Racine Ave. | 7 | 37.3 | 23.3 | 30.3 | 40.0 | 44.6 | .......... | |
| Ashland Ave. | 8 | 43.0 | 33.6 | 38.3 | 45.3 | 51.1 | .......... | 5 days |
| Grand Total | .......... | 110.2 | 82.8 | 96.5 | 119.3 | 138.6 | .......... | |
| Percent Industrial is of Total | .......... | 59.5 | 37.5 | 50.0 | 61.9 | 74.5 | .......... | |

## TABLE 114

PACKINGTOWN SEWER INVESTIGATIONS—1917

Total and Percentage Flow by Individual Firms

| Firm | Cu. Ft. per Sec. | | Percent of Total Excluding U. S. Y. Co. | | Percent of Total Including U. S. Y. Co. | |
|---|---|---|---|---|---|---|
| | Day 7 a.m. to 7 p.m. | 24 Hours | Day 7 a.m. to 7 p.m. | 24 Hours | Day 7 a.m. to 7 p.m. | 24 Hours |
| Swift & Co. | 18.67 | 14.21 | 31.80 | 31.73 | 28.02 | 29.12 |
| Armour & Co. | 17.75 | 14.39 | 30.23 | 32.14 | 26.63 | 29.49 |
| Union Stockyards Co. | 7.92* | 4.01* | ........ | ........ | 11.88 | 8.22 |
| Morris & Co. | 7.03* | 5.93 | 11.97 | 13.24 | 10.54 | 12.15 |
| Wilson & Co. | 5.36 | 4.06 | 9.14 | 9.06 | 8.04 | 8.33 |
| Hammond & Co. | 2.38 | 1.53 | 4.05 | 3.42 | 3.57 | 3.14 |
| Libby, McNeil & Libby | .96 | 1.07 | 1.64 | 2.39 | 1.44 | 2.20 |
| Independent Packing Co. | .86 | .43 | 1.47 | 0.96 | 1.29 | .88 |
| John Agar Co. | .62 | .34 | 1.06 | 0.76 | .93 | .70 |
| Western Packing Co. | .53 | .26 | .90 | .58 | .80 | .53 |
| Guggenheim Bros. | .43 | .22 | .73 | .49 | .65 | .45 |
| Boyd-Lunham Co. | .43 | .22 | .73 | .49 | .65 | .45 |
| Darling & Co. | .40 | .37 | .68 | .83 | .60 | .76 |
| Brennan Packing Co. | .39 | .20 | .66 | .45 | .59 | .41 |
| Peerless Packing Co. | .33 | .17 | .56 | .38 | .50 | .35 |
| Oppenheimer Casing Co. | .32 | .16 | .54 | .36 | .48 | .33 |
| Chicago Packing Co. | .27 | .22 | .46 | .49 | .40 | .45 |
| Anglo-American Prov. Co. | .26 | .13 | .44 | .29 | .39 | .27 |
| L. Pfaelzer & Sons | .25 | .13 | .43 | .29 | .38 | .27 |
| Bechstein & Co. | .22 | .11 | .37 | .25 | .33 | .23 |
| Miller & Hart | .21 | .11 | .36 | .25 | .32 | .23 |
| American Gut String Co. | .20 | .10 | .34 | .22 | .30 | .20 |
| Siegel-Hechinger | .18 | .09 | .31 | .20 | .27 | .18 |
| No. American Prov. Co. | .14 | .07 | .24 | .16 | .21 | .14 |
| Roberts & Oake | .12 | .06 | .20 | .13 | .18 | .12 |
| Friedman Mfg. Co. | .12 | .06 | .20 | .13 | .18 | .12 |
| Northwestern Glue Co. | .09 | .05 | .15 | .11 | .14 | .10 |
| D. Levi | .08 | .04 | .14 | .09 | .12 | .08 |
| J. J. Cullinan | .06 | .03 | .10 | .07 | .09 | .06 |
| J. R. Beiersdorf & Bro. | .03 | .01 | .05 | .02 | .04 | .02 |
| B. Pfaelzer | .03 | .01 | .05 | .02 | .04 | .02 |
| Total | | | | | | |
| Excluding Union S. Y. Co. | 58.72 | 44.78 | 100.00 | 100.00 | ........ | ........ |
| Including Union S. Y. Co. | 66.64 | 48.79 | ........ | ........ | 100.00 | 100.00 |

*Estimated

STOCKYARDS TESTS, 1919. In order to check up on the proportion of total pollution traceable to the Union Stockyards and Transit Company, a few additional tests were made at the Morgan St. outlet and some of the other outlets tributary to the Ravine Ave. sewers during one week in October, 1919 (Table 119). For the Morgan St. sewer, the tests were continued over a period of 12 hours, while for the others, the tests were in progress between the hours of 8 a. m. and 4 p. m. only. The flow figures for the latter tests, however, have been adjusted to a 12 hour period, by assuming the flow during the remaining 4 hours as zero, in order to make the results comparable with the rest of the data reported. In general the 1919 tests indicate that the results obtained by prorating the results obtained at Morgan St. over the entire Stockyards area were substantially correct. However the volume of flow

at Morgan St. had increased considerably over the results obtained in 1917. This may be due in part to the much heavier shipment of animals during the test period in 1919, than in 1917 (Table 120), and in part to different distribution of the animals in the pens.

The analyses indicate that the discharge from the hog pens is somewhat stronger than that from the cattle pens. No tests were made on sewers from the sheep pens, which are largely covered, where the amount of waste per animal is relatively small.

## TABLE 115

PACKINGTOWN SEWER INVESTIGATIONS—1917

Daily Discharge of Suspended Matter, Organic Nitrogen and Biologic Oxygen Demand
Individual Firms

| Firm | Pounds per 24 Hours | | | Percent of Total | | |
|---|---|---|---|---|---|---|
| | Total Susp. Matter | Organic Nitrogen | Biologic Oxygen Demand | Total Susp. Matter | Organic Nitrogen | Biologic Oxygen Demand |
| Swift & Co. | 52,170 | 3,756 | 74,050 | 39.67 | 28.24 | 30.53 |
| Armour & Co. | 25,120 | 2,436 | 48,370 | 19.10 | 18.32 | 19.94 |
| Morris & Co. | 18,850 | 2,058 | 36,000 | 14.34 | 15.48 | 14.84 |
| Wilson & Co. | 10,110 | 1,363 | 22,130 | 7.69 | 10.25 | 9.12 |
| Hammond & Co. | 3,620 | 379 | 9,070 | 2.76 | 2.86 | 3.74 |
| Union Stock Yards Co. | 3,520* | 158* | 2,460* | 2.68 | 1.19 | 1.02 |
| Libby, McNeil & Libby | 3,030 | 235 | 6,640 | 2.31 | 1.77 | 2.74 |
| Darling & Co. | 2,200 | 528 | 6,520 | 1.67 | 3.98 | 2.69 |
| Guggenheim Bros. | 1,480 | 144 | 5,800 | 1.13 | 1.08 | 2.39 |
| Independent Packing Co. | 1,450 | 193 | 3,320 | 1.10 | 1.45 | 1.37 |
| Boyd-Lunham | 1,230 | 218 | 2,170 | .94 | 1.64 | .90 |
| Peerless Packing Co. | 1,000 | 206 | 2,510 | .76 | 1.55 | 1.03 |
| Chicago Packing Co. | 960 | 143 | 2,700 | .73 | 1.08 | 1.11 |
| John Agar Co. | 870 | 270 | 3,880 | .66 | 2.03 | 1.60 |
| Oppenheimer Casing Co. | 810 | 233 | 2,770 | .62 | 1.75 | 1.14 |
| Brennan Packing Co. | 790 | 189 | 1,630 | .60 | 1.42 | .67 |
| Anglo American Prov. Co. | 700 | 55 | 1,010 | .53 | .41 | .42 |
| Bechstein & Co. | 560 | 118 | 1,800 | .43 | .89 | .74 |
| Western Packing Co. | 490 | 78 | 1,290 | .37 | .58 | .53 |
| Roberts & Oake | 440 | 118 | 1,200 | .33 | .89 | .49 |
| Miller & Hart | 420 | 83 | 1,550 | .32 | .62 | .64 |
| L. Pfaelzer & Sons | 280 | 36 | 810 | .21 | .27 | .33 |
| Siegel-Hechinger | 260 | 84 | 1,530 | .20 | .63 | .63 |
| Friedman Mfg. Co. | 240 | 25 | 580 | .18 | .19 | .24 |
| Northwestern Glue Co. | 200 | 66 | 840 | .15 | .49 | .35 |
| No. American Prov. Co. | 190 | 49 | 850 | .14 | .37 | .35 |
| D. Levi | 190 | 26 | 420 | .14 | .20 | .17 |
| J. J. Cullinan | 100 | 18 | 450 | .07 | .13 | .19 |
| American Gut String Co. | 90 | 11 | 130 | .07 | .08 | .05 |
| J. R. Beiersdorf | 110 | 18 | 50 | .08 | .13 | .02 |
| B. Pfaelzer | 20 | 4 | 40 | .02 | .03 | .02 |
| Total | 131,500 | 13,298 | 242,570 | 100.00 | 100.00 | 100.00 |

*Estimated

## TABLE 116

PACKINGTOWN SEWER INVESTIGATIONS—1917

Estimated Percentage Liability for Cost of Disposal Plant. Individual Firms

| Firm | Percent of Total | | | Percent of Total Depending on | | | | Percentage Liability |
|---|---|---|---|---|---|---|---|---|
| | Day Flow 7 a.m. to 7 p.m. | Suspended Matter 24 Hrs. | Day B. O. C. 7 a.m. to 7 p.m. | Day Flow Only | Suspended Matter Only | Day Flow and B. O. C. | | |
| | | | | | | Flow | B. O. C. | |
| Swift & Co. | 28.02 | 39.67 | 29.59 | 4.20 | 11.90 | 7.70 | 8.14 | 31.94 |
| Armour & Co. | 26.64 | 19.10 | 19.34 | 4.00 | 5.73 | 7.34 | 5.32 | 22.39 |
| Morris & Co. | 10.55 | 14.33 | 13.66 | 1.58 | 4.30 | 2.90 | 3.75 | 12.53 |
| Wilson & Co. | 8.04 | 7.69 | 8.46 | 1.20 | 2.31 | 2.21 | 2.33 | 8.05 |
| Union Stockyards Co. | 11.88 | 2.68 | 1.16 | 1.78 | .80 | 3.27 | .32 | 6.17 |
| Hammond & Co. | 3.57 | 2.76 | 4.15 | .53 | .83 | .98 | 1.13 | 3.47 |
| Libby, McNeil & Libby | 1.44 | 2.31 | 2.34 | .21 | .69 | .40 | .64 | 1.94 |
| Darling & Co. | .60 | 1.67 | 2.76 | .09 | .50 | .16 | .76 | 1.51 |
| Guggenheim Bros. | .65 | 1.13 | 2.87 | .10 | .34 | .18 | .79 | 1.41 |
| Independent Packing Co. | 1.29 | 1.10 | 1.78 | .19 | .33 | .36 | .49 | 1.37 |
| John Agar Co. | .93 | .66 | 1.92 | .14 | .20 | .26 | .53 | 1.13 |
| Boyd-Lunham Co. | .65 | .94 | 1.16 | .10 | .28 | .18 | .32 | .88 |
| Oppenheimer Casing Co. | .48 | .62 | 1.49 | .07 | .19 | .13 | .41 | .80 |
| Chicago Packing Co. | .40 | .73 | 1.29 | .06 | .22 | .11 | .35 | .74 |
| Peerless Packing Co. | .49 | .76 | .99 | .07 | .23 | .13 | .27 | .70 |
| Brennan Packing Co. | .59 | .60 | .88 | .09 | .18 | .16 | .24 | .67 |
| Western Packing Co. | .80 | .37 | .69 | .12 | .11 | .22 | .19 | .64 |
| Beckstein & Co. | .33 | .43 | .97 | .05 | .13 | .09 | .27 | .54 |
| Anglo-American Prov. Co. | .39 | .53 | .54 | .06 | .16 | .11 | .15 | .48 |
| Miller & Hart | .32 | .32 | .83 | .05 | .10 | .09 | .23 | .47 |
| Roberts & Oake | .18 | .34 | .64 | .03 | .10 | .05 | .17 | .35 |
| L. Pfaelzer & Sons | .38 | .21 | .43 | .06 | .06 | .10 | .12 | .34 |
| No. American Prov. Co. | .21 | .14 | .46 | .03 | .04 | .06 | .13 | .26 |
| Siegel-Hechinger | .27 | .20 | .29 | .04 | .06 | .07 | .08 | .25 |
| Friedman Mfg. Co. | .18 | .18 | .31 | .03 | .05 | .05 | .09 | .22 |
| Northwestern Glue Co. | .13 | .15 | .41 | .02 | .05 | .04 | .11 | .22 |
| American Gut String Co. | .30 | .07 | .07 | .05 | .02 | .08 | .02 | .17 |
| D. Levi | .12 | .14 | .23 | .02 | .04 | .03 | .06 | .15 |
| J. J. Cullinan | .09 | .07 | .24 | .01 | .02 | .02 | .07 | .12 |
| J. R. Beiersdorf & Bro. | .04 | .08 | .03 | .01 | .02 | .01 | .01 | .05 |
| B. Pfaelzer | .04 | .02 | .02 | .01 | .01 | .01 | .01 | .04 |
| Total | 100.00 | 100.00 | 100.00 | 15.00 | 30.00 | 27.50 | 27.50 | 100.00 |

Percentage of total cost depending on day flow=15.
Percentage of total cost depending on total suspended matter=30.
Percentage of total cost depending on day flow and B. O. C. (given equal weight)=55.
These percentages are figured from detailed estimates for cost of plant in report of Messrs. Pearse and Richardson, April 16, 1917.

## TABLE 117

FLOW IN MAIN SEWERS

| Sewer | Flow in Cu. Ft. per Sec. | | | |
|---|---|---|---|---|
| | 1911 | | 1917 | |
| | Day 8 a. m. to 8 p. m. | 24 Hr. | Day 8 a. m. to 8 p. m. | 24 Hr. |
| Halsted St., 4 Ft. | 6.5* | 5.9* | 3.9 | 3.8 |
| Halsted St., 7 Ft. | 35.1* | 32.6* | 21.9 | 21.6 |
| Racine Ave. | 25.6 | 21.3 | 37.3 | 30.3 |
| Ashland Ave. | 28.5 | 23.5 | 43.0 | 38.3 |

*1915

## TABLE 118

PACKINGTOWN SEWERS INVESTIGATION—1917

Ether—Soluble Matter—Individual Outlets

| Firm | Outlet | Date 1917-18 | Petroleum Ether—Soluble Parts per Million | |
|---|---|---|---|---|
| | | | Non-Acid | Acid |
| Swift & Co. | 42nd and Ashland | Dec. 17 to 19 | 128 | 212 |
| | 41st and Ashland | Dec. 20 to 22 | 320 | 519 |
| | Wool House | Dec. 17 to 19 | 176 | 212 |
| | Packers and River | Dec. 20 to 22 | 215 | 202 |
| | 42nd and Racine | Dec. 13 to 15 | 110 | 241 |
| | Exchange and Racine | Dec. 13 to 15 | 130 | 158 |
| Armour & Co. | 43rd and Racine | Dec. 10 to 12 | 107 | 154 |
| | 43rd Pl. and Racine | Dec. 10 to 12 | 201 | 285 |
| | 44th and Racine | Dec. 10 to 12 | 135 | 196 |
| Morris & Co. | 44th and Ashland | Jan. 2 to 5 | 156 | 308 |
| | 42nd and Ashland | Dec. 17 to 19 | 78 | 104 |
| | Exchange and Racine | Dec. 13 to 15 | 386 | 671 |
| Wilson & Co. | Ashland Ave. | Jan. 7 to 9 | 116 | 111 |
| Brennan Packing Co. | 39th St. Conduit | Dec. 3 to 8 | 102 | 290 |
| Boyd-Lunham | Racine | Dec. 24 to 31 | 206 | ..... |

## TABLE 119

PACKINGTOWN SEWER INVESTIGATIONS—OCTOBER 1919

Stockyards Sewers—Day Flow Measurements and Analyses

| Sewer Outlet 1919 | Approximate Drainage Area Acres | Day (12-Hr.) Flow C. F. P. S. | | Parts per Million | | | | | | | Pounds per 24 Hours | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Suspended Matter | | | Oxygen Cons. | Nitrogen as | | Biologic Oxygen Demand | Suspended Matter | Org. N. | Biologic Oxygen Demand |
| | | Total | Per Acre | Total | Volatile | Fixed | | Free Amm. | Org. N. | | | | |
| Morgan St. | 27 | 1.93 | 0.071 | 188 | 114 | 74 | 54 | 5.3 | 10.2 | 100 | 1010 | 51 | 480 |
| Hog Pen—338 | 6.3 | 0.65 | 0.103 | 154 | 107 | 47 | 53 | 5.6 | 10.7 | 120 | 240 | 17 | 250 |
| Hog Pen—483 | 7.1 | 0.86 | 0.121 | 347 | 201 | 146 | 81 | 8.6 | 19.3 | 180 | 640 | 38 | 380 |
| Cattle Pen, D-10—722 | 18.0 | ...... | ...... | 299 | 198 | 101 | 71 | 6.9 | 18.3 | 110 | ...... | ... | ...... |
| Cattle Pen, D-16-25 | 16.4 | ...... | ...... | 100 | 74 | 26 | 49 | 3.7 | 5.8 | 60 | ...... | ... | ...... |
| Cattle Pen, D-12—90 | 14.4 | ...... | ...... | 100 | 73 | 27 | 43 | 2.4 | 3.9 | 50 | ...... | ... | ...... |
| Cattle—South A. | 16.0 | 0.31 | 0.019 | 138 | 95 | 43 | 65 | 4.2 | 8.4 | 60 | 150 | 5 | 50 |
| Avg. Excluding Morgan St. | ...... | ...... | 0.081 | 190 | 125 | 65 | 60 | 5.2 | 11.1 | 100 | ...... | ... | ...... |
| Morgan St.—1917 | 27 | 1.10 | 0.041 | 179 | 124 | 55 | 36 | 3.6 | 8.5 | 110 | 490 | 22 | 300 |

## TABLE 120

AVERAGE DAILY RECEIPTS OF LIVE STOCK IN STOCKYARDS

| Average Daily Number Received | 1917 | 1919 |
|---|---|---|
| Cattle | 11,960 | 13,476 |
| Calves | 1,479 | 2,896 |
| Hogs | 9,464 | 18,390 |
| Sheep | 13,442 | 31,366 |
| Total | 36,345 | 66,128 |

## APPENDIX 3.

### GREASE RECOVERY.

GENERAL. The problem of sewage treatment would not be complete without a description of the methods in vogue for grease recovery and a note of the results obtained.

DESCRIPTION OF PLANTS. Three skimming plants are operated at the outlet of the Center Avenue sewer by Armour & Co., Morris & Co., and Fitzpatrick Bros., in order of progression toward the outlet.

The Armour Plant consists of a baffled basin 84 feet by 19 feet in plan with a flow depth of about 6 feet. A central baffle, dividing the basin into two equal parts and extending to the bottom for nearly the entire length, forces the sewage to travel a total distance of about 160 feet in passing through. Cross baffles at intervals of about 8 feet with a clearance above the bottom of about 1.3 feet serve to hold back the scum. A portion only of the flow is diverted to the plant by a weir built in the sewer. The effluent is turned back into the sewer. The basin is roofed over.

The Morris basin is located immediately adjacent to the outlet of the sewer and is 100 feet long and 14 feet wide. As operated at the time of sampling, the flow depth was about 3 feet. A portion only of the discharge is diverted to this basin by an overflow weir at the sewer outlet. The basin is divided lengthwise into two equal parts by a baffle extending to the floor. Eleven underflow cross baffles with a clearance of 1.5 feet above the bottom, hold back the greasy scum which rises. The flow is directly through the basin from one end to the other and the effluent discharges through 5 ports into the river.

The Fitzpatrick plant merely consists of a baffle, floating in the river and approximately parallel to the bank, at a distance of about 30 feet. This extends along the shore for a distance of about 300 feet. Several cross baffles are provided. The plant is arranged so that the entire flow of the sewer, including the discharge from the Morris basin, is handled.

Similar skimming plants were maintained at the outlet of the Ashland Avenue sewer, but were not examined. These were abandoned in December, 1916, upon the completion of the Stock-yards intercepting sewer along the south bank of Bubbly Creek, west of Ashland Avenue.

OPERATION. A man is kept at each plant continuously during the day time. As the greasy scum rises to the surface, it is frequently skimmed off and placed in barrels which are removed at frequent intervals. A record was kept of the amount of scum thus removed for a period of three weeks in March, 1915, and again in January 1917, exclusive of Sundays, (table 121).

**TABLE 121**

CENTER AVE. SEWER

Record of Grease Skimming in Barrels.

| Basin | Mar. 8 to 27, 1917 | | Jan. 9 to 13, 1917 | | Jan. 5 to 20, 1917 | |
|---|---|---|---|---|---|---|
| | Total | Average per Day | Total | Average per Day | Total | Average per Day |
| Armour | 250 | 14 | 175 | 29 | 145 | 24 |
| Morris | 54 | 3 | 12 | 2 | 36 | 6 |
| Fitzpatrick | 233 | 13 | 250 | 42 | 325 | 56 |
| Total | 537 | 30 | 437 | 73 | 506 | 86 |

COMPOSITION OF SKIMMINGS. Samples of the skimmings have been analyzed with the results given herewith (table 122).

**TABLE 122**

ANALYSES OF SKIMMINGS FROM GREASE BASINS

| Date | Location | Sp. Gr. | Moisture Percent | Dry Basis—Percentage | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | N | Vol. Matter | Fixed Matter | Ether Soluble | |
| | | | | | | | Non-Acid | Acid |
| 1914 | | | | | | | | |
| Dec. 30 | Armour | 0.98 | 46.4 | 0.34 | 98.0 | 2.0 | 86.5 | 86.6 |
| Dec. 30 | Fitzpatrick | 1.00 | 44.4 | 0.76 | 97.2 | 2.8 | 80.5 | 83.1 |
| 1915 | | | | | | | | |
| Jan. 4 | Morris | 1.00 | 45.6 | 1.08 | 97.4 | 2.6 | 79.7 | 79.1 |
| 1917 | | | | | | | | |
| Jan. 8 | Armour | ........ | 65.7 | ........ | ........ | ........ | 86.1* | ........ |
| Jan. 9 | Armour | ........ | 61.8 | ........ | ........ | ........ | 77.1* | ........ |
| Jan. 10 to 13 | Armour | 0.938 | 62.0 | ........ | ........ | ........ | 80.1* | 61.9* |

*Petroleum Ether Used in Tests

The moisture content as handled in the barrels is low. The nitrogen content is low compared with the tank sludges. However, the grease, which is non-nitrogenous, forms such a large proportion of the dry matter, that after removal, the residue would be relatively high in nitrogen. The fat content is very high. The skimmings from the Armour basin, which receives the first flow are somewhat higher in fat than the others.

RECOVERY. The recovery in 1915 was estimated from the ether soluble determination. Taking this as 45 per cent. of the total weight of the scum and assuming that all the scum forms between 8 a. m. and 10 p. m. with an average flow of 30 cubic feet per second, an equivalent removal of about 30 p. p. m. of ether soluble material resulted. The day sewage during this period discharged by the grit chamber averaged 158 p.p.m. of ether soluble material. This would indicate a removal of about 19 percent by the three skimming basins.

On the other hand in 1916, a record was kept for a month of the skimmings and the amount of recovery. From February 28 to March 29, 170 barrels containing 48,010 lb. of raw skimmings were removed from the Ashland Ave. catch basin. From this was extracted 6,449 lb. of grease.

In 1917, from January 8 to 13, Armour collected 40,866 lb. of scum from Center Ave. of which 5,850 lb. or 14.3 percent was extracted as grease. The analyses showed an ether soluble content of about 29.5 percent on a wet basis, or 12,080 lb. ether soluble material. The extraction therefore showed a recovery of 48.4 percent of the ether soluble material as grease.

On the 1917 figures, during the period January 9 to 20, taking the Armour figures as a basis (175 bbl. = 40,866 lb. scum = 5,850 lb. grease), we have one barrel as equivalent to 235 lb. of scum or 33.4 lb. of extracted grease. Based on these figures and taking the skimming at Center Ave. as 80 barrels per day, the recovery would be 18,649 lb. of scum or 2,672 lb. of grease per day. This amount will vary with the killing and the weather.

COMMENT. The value of the skimmings varies greatly. Under present conditions somewhat less than 50 percent of the ether soluble content is extracted as grease. The rising of the greasy scum appears to be due to the combined effect of slow velocity through the basins, with opportunity for the lighter particles to rise behind baffles. There is reason to believe that churning and agitation is helpful in bringing the grease to the surface.

# APPENDIX 4.

## SUMMARY.

Reprinted from

## REPORT ON INDUSTRIAL WASTES FROM THE STOCKYARDS AND PACKINGTOWN IN CHICAGO.

October, 1914.

GENERAL. Some two years ago negotiations were begun with the firms in the Stockyards and Packingtown by which a testing station was put in operation on Center Ave. in September, 1912. Engineering studies were made on various alternatives for sewers in handling industrial wastes. It was early recognized that in such development some heed should be paid to the possible future requirements both for sewerage and sewage disposal, as the U. S. government has been seeking to enjoin the Sanitary District from diverting more than 4,167 cubic feet per second from Lake Michigan. The suit is not yet decided.

Last year a movement was started to fill up Bubbly Creek, that is, the west arm of the south fork of the south branch of the Chicago River. This would reclaim a certain amount of space, now useless, and would permanently remove from the vicinity of Packingtown the present river nuisance. Unless steps were taken, however, to reduce the organic load this removal itself would only transfer the present trouble to other localities.

WESTERN AVE. CONDUIT. In 1909, a conduit was built from the west end of the west arm of Bubbly Creek north to and along West 39th St. to Western Ave. and thence north to the Drainage Canal at 31st St. This conduit was expected to cause a circulation in the then stagnant west arm by utilizing a slight difference of head. But continued use for over four years has not proven this adequate. Material settles in the west arm as markedly as before. A recent inspection of the conduit has shown deposits

from two to four feet deep, due to low velocities, and a much reduced flow, at present about 73 cubic feet per second, practically the flow of Western Ave. and Robey St. sewers plus Ashland Ave. In the present condition of the conduit, this flow appears largely independent of the working of the flushing pumps at 39th Street and Lake Michigan.

DREDGING. Dredging was carried out last year at a total expense of $34,534.05, of which the committee of packers and the stockyards paid $26,864.38. This affords, however, only temporary relief, since the dredged spots fill in again and all the while the deposits on the bottom become septic, blow up, form scum and give the disagreeable appearance from which the characteristic name "Bubbly Creek" was derived.

TESTING STATION. The testing station investigations at Center Ave. have been extended beyond the original program, because certain additional experiments were found necessary to study the treatment of settled sewage on sprinkling filters and the behavior of devices under a longer trial than one year. Other special tests on sludge handling, recovery of fats and the like are still under way. The formulation of a new method of testing effluents early in 1914, by our Chemist, Dr. Lederer, also emphasized the need of learning at some length the comparative oxygen requirements of domestic sewage, as well as packingtown wastes and other industrial sewage.

The original testing station layout (1912) was equipped with a coarse screen with ⅝ in. clear openings, a 2 in. contrifugal pump, a grit chamber, Emscher tank and Dortmund tank. To this has been added a fine mesh (30 meshes to the inch) rotary screen of the Weand type, a sprinkling filter and a chemical precipitation tank with devices for mixing and applying chemicals. A screen testing device was also added, as well as sedimentation cans.

CRUDE SEWAGE. The sewage at both Center Ave. and Ashland Ave. outlets is very strong, containing large amount of both suspended and soluble matter (Table 123). At different hours of the day, the crude sewage varies greatly in strength according to the discharge of wastes from the stockyards and Packingtown. The average analyses for the year 1913 for the day and night flow from Center Ave. sewer are given in Table 124. The character of the night flow and the Sunday flow was practically identical. Some

## TABLE 123

ANALYSES OF SEWAGE FROM 39TH ST., STOCKYARDS, PACKINGTOWN, AND OTHER SEWERS

Results in Parts per Million

| Determinations | 39TH ST. | | HALSTED ST. | | Morgan St. (3) | CENTER AVE.—1913 | | ASHLAND AVE. | | | Robey St. (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1909 to 1912 | 1913 | North (1) | South (2) | | 8 a.m. to 11 p.m. Day | 11 p.m. to 8 a.m. Night | J.H.Long 1890 24 days | Day (6) | Night (6) | |
| Nitrogen as:— | | | | | | | | | | | |
| Free Ammonia | 9.1 | 8.6 | 28 | 19 | ...... | 22 | ...... | ...... | 20 | 18 | 29.6 |
| Organic N. | 7.8 | 6.6 | 260 | 10.4 | ...... | 79 | ...... | ...... | 73 | 34 | 8.4 |
| Nitrites | 0.10 | 0.09 | ...... | ...... | ...... | 0.49 | ...... | ...... | 0.21 | 0.08 | 0.07 |
| Nitrates | 0.38 | 0.24 | ...... | ...... | ...... | 3.04 | ...... | ...... | 1.97 | 0.86 | 0.31 |
| Oxygen Consumed | 43 | 37 | 257 | 60 | 202 | 268 | ...... | 429 | 245 | 70 | 51 |
| Chlorine | 40 | 38 | 365 | 56 | ...... | 1100 | ...... | 1895 | 920 | 537 | 261 |
| Alkalinity | 212 | 198 | 340 | 222 | ...... | 291 | ...... | ...... | 358 | 237 | 464 |
| Suspended Matter:— | | | | | | | | | | | |
| Total | 144 | 131 | 428 | 176 | 548 | 605 | 160 | 894 | 860 | 258 | 63 |
| Volatile | 90 | 81 | 344 | 88 | 401 | 461 | 108 | 706 | 657 | 120 | 40 |
| Fixed | 54 | 50 | 84 | 88 | 147 | 144 | 52 | 188 | 203 | 138 | 23 |
| Fats | 23 (8) | ...... | ...... | ...... | 226 (4) | 226 (4) | 123 (4a) | ...... | ...... | ...... | ...... |
| | ...... | ...... | ...... | ...... | 153 (5) | 153 (5) | ...... | ...... | ...... | ...... | ...... |

1—July 28, 1911, 4 hr.
2—July 29, 1911, 4 hr.
3—Ninety-five days in 1911
4—Eighty days, winter, 8 a.m. to 8 p.m.
4a—Eight days, winter, 8 p.m. to 8 a.m.
5—Five weeks, April and May, 1914.
6—Fourteen day samples, ten night samples, 1913
7—Three days, May 31 to June 3, 1911
8—Approximately four months' record

## TABLE 124

MONTHLY AVERAGES—CHEMICAL ANALYSES OF CRUDE SEWAGE—CENTER AVE. SEWER

| Date | Parts per Million | | | | | | | | | | Sampling Period |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nitrogen as | | | | Oxygen Cons. | Chlorine | Suspended Matter | | | Alkalinity in terms of $CaCO_3$ | |
| | Total Organic | Free Amm. | Nitrites | Nitrates | Total | | Total | Volatile | Fixed | | |
| **DAY SEWAGE—SUNDAYS OMITTED** | | | | | | | | | | | |
| 1912 | | | | | | | | | | | |
| October | 105 | 23 | .44 | 1.64 | 282 | 1078 | 719 | 599 | 120 | 326 | 8 a.m. to 7 p.m., (Inclusive) |
| November | 127 | 28 | .53 | 2.46 | 339 | 1190 | 769 | 590 | 179 | 342 | 8 a.m. to 7 p.m., (Inclusive) |
| December | 119 | 26 | .44 | 3.43 | 342 | 1125 | 731 | 576 | 155 | 305 | 8 a.m. to 7 p.m., (Inclusive) |
| 1913 | | | | | | | | | | | |
| January | 96 | 24 | .44 | 3.14 | 322 | ...... | 702 | 543 | 159 | ...... | 7 a.m. to 10 p.m., (Inclusive) |
| February | 91 | 25 | .50 | 3.22 | 317 | ...... | 660 | 510 | 150 | ...... | 8 a.m. to 10 p.m., (Inclusive) |
| March | 71 | 19 | .49 | 2.97 | 267 | 996 | 591 | 451 | 140 | 291 | 8 a.m. to 10 p.m., (Inclusive) |
| April | 70 | 20 | .51 | 2.91 | 250 | 1150 | 556 | 422 | 134 | 293 | 8 a.m. to 10 p.m., (Inclusive) |
| May | 80 | 22 | .64 | 2.97 | 258 | 1134 | 658 | 470 | 188 | 291 | 8 a.m. to 10 p.m., (Inclusive) |
| June | 81 | 21 | .64 | 2.96 | 264 | 1121 | 603 | 428 | 175 | 248 | 8 a.m. to 10 p.m., (Inclusive) |
| July | 71 | 21 | .51 | 3.47 | 240 | 1096 | 568 | 428 | 140 | 274 | 8 a.m. to 10 p.m., (Inclusive) |
| August | 74 | 22 | .47 | 3.13 | 228 | 1110 | 574 | 413 | 161 | 304 | 8 a.m. to 10 p.m., (Inclusive) |
| September | 76 | 21 | .49 | 2.85 | 250 | 1128 | 621 | 498 | 123 | 319 | 8 a.m. to 10 p.m., (Inclusive) |
| October | 69 | 22 | .38 | 2.41 | 251 | 1023 | 519 | 415 | 104 | 246 | 8 a.m. to 10 p.m., (Inclusive) |
| November | 86 | 24 | .44 | 3.00 | 282 | 1072 | 617 | 481 | 136 | 310 | 8 a.m. to 10 p.m., (Inclusive) |
| December | 89 | 24 | .38 | 3.70 | 287 | 1170 | 595 | 476 | 119 | 331 | 8 a.m. to 10 p.m., (Inclusive) |
| Average, 1913 | 79 | 22 | .49 | 3.04 | 268 | 1100 | 605 | 461 | 144 | 291 | |

**TABLE 124—Continued**

MONTHLY AVERAGES—CHEMICAL ANALYSES OF CRUDE SEWAGE—CENTER AVE. SEWER

| Date | Parts per Million | | | | | | | | | | Sampling Period |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nitrogen as | | | | Oxygen Cons. | Chlorine | Suspended Matter | | | Alkalinity in terms of CaCo3 | |
| | Total Organic | Free Amm. | Nitrites | Nitrates | Total | | Total | Volatile | Fixed | | |
| NIGHT SAMPLES—SUNDAYS INCLUDED | | | | | | | | | | | |
| 1912 | | | | | | | | | | | |
| October | 49 | 17 | .27 | 1.09 | 149 | 715 | 415 | 320 | 95 | 276 | 8 p.m. to 7 a.m., (Inclusive) |
| November | 50 | 22 | .20 | 1.28 | 142 | 800 | 363 | 238 | 125 | 259 | 8 p.m. to 7 a.m., (Inclusive) |
| December | 52 | 20 | .21 | 1.30 | 131 | 655 | 334 | 244 | 90 | 222 | 8 p.m. to 7 a.m., (Inclusive) |
| January | | | | | | | 225 | 152 | 73 | | 11 p.m. to 6 a.m., (Inclusive) |
| February | | | | | | | 161 | 112 | 49 | | 11 p.m. to 7 a.m., (Inclusive) |
| March | | | | | | | 158 | 111 | 47 | | 11 p.m. to 7 a.m., (Inclusive) |
| April | | | | | | | 119 | 81 | 38 | | 11 p.m. to 7 a.m., (Inclusive) |
| May | | | | | | | 221 | 141 | 80 | | 11 p.m. to 7 a.m., (Inclusive) |
| June | | | | | | | 158 | 99 | 59 | | 11 p.m. to 7 a.m., (Inclusive) |
| July | | | | | | | 152 | 92 | 60 | | 11 p.m. to 7 a.m., (Inclusive) |
| August | | | | | | | 130 | 87 | 43 | | 11 p.m. to 7 a.m., (Inclusive) |
| September | | | | | | | 171 | 114 | 57 | | 11 p.m. to 7 a.m., (Inclusive) |
| October | | | | | | | 125 | 91 | 34 | | 11 p.m. to 7 a.m., (Inclusive) |
| November | | | | | | | 141 | 101 | 40 | | 11 p.m. to 7 a.m., (Inclusive) |
| December | | | | | | | 160 | 115 | 45 | | 11 p.m. to 7 a.m., (Inclusive) |
| Average, 1913 | | | | | | | 160 | 108 | 52 | | 11 p.m. to 7 a.m., (Inclusive) |

# TABLE 124—Continued

MONTHLY AVERAGES—CHEMICAL ANALYSES OF CRUDE SEWAGE—CENTER AVE. SEWER

| Date | Parts per Million | | | | | | | | | | Sampling Period |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nitrogen as | | | | Oxygen Cons. | Chlorine | Suspended Matter | | | Alkalinity in terms of $CaCO_3$ | |
| | Total Organic | Free Amm. | N trites | Nitrates | Total | | Total | Volatile | Fixed | | |
| DAY AND NIGHT (24 HOUR) SAMPLES—SUNDAYS OMITTED | | | | | | | | | | | |
| 1912 | | | | | | | | | | | |
| October | 90 | 22 | .40 | 1.43 | 248 | 1000 | 643 | 519 | 124 | 314 | |
| November | 94 | 26 | .37 | 2.21 | 253 | 1037 | 589 | 431 | 158 | 314 | |
| December | 89 | 24 | .35 | 1.92 | 252 | 910 | 540 | 420 | 120 | 265 | |
| 1913 | | | | | | | | | | | |
| January | ... | ... | ... | ... | ... | ... | 542 | 413 | 129 | ... | |
| February | ... | ... | ... | ... | ... | ... | 483 | 366 | 117 | ... | |
| March | ... | ... | ... | ... | ... | ... | 433 | 329 | 104 | ... | |
| April | ... | ... | ... | ... | ... | ... | 394 | 296 | 98 | ... | |
| May | ... | ... | ... | ... | ... | ... | 500 | 350 | 150 | ... | |
| June | ... | ... | ... | ... | ... | ... | 444 | 310 | 134 | ... | |
| July | ... | ... | ... | ... | ... | ... | 418 | 312 | 106 | ... | |
| August | ... | ... | ... | ... | ... | ... | 425 | 302 | 123 | ... | |
| September | ... | ... | ... | ... | ... | ... | 437 | 350 | 87 | ... | |
| October | ... | ... | ... | ... | ... | ... | 374 | 295 | 79 | ... | |
| November | ... | ... | ... | ... | ... | ... | 444 | 343 | 101 | ... | |
| December | ... | ... | ... | ... | ... | ... | 436 | 345 | 91 | ... | |
| Average, 1913 | ... | ... | ... | ... | ... | ... | 444 | 334 | 110 | ... | |

seasonal variation in strength occurred, the sewage being weakest during the spring and summer and attaining a maximum strength during late fall and early winter. The great strength of the day sewage is clearly shown by comparison with the purely domestic sewage from 39th St. sewage pumping station (Table 125). At Center Ave. a biologic oxygen consumption of roughly 1,000 p.p.m. was found for the crude day sewage, whereas at 39th St. this was only 100 to 150 p.p.m.

## TABLE 125

COMPARATIVE ANALYSES OF SEWAGE OF VARIOUS AMERICAN CITIES AND DAY SEWAGE AT STOCKYARDS

| | Parts per Million | | | | | | |
|---|---|---|---|---|---|---|---|
| | Boston* 1905-7 | Columbus *a* 1904-5 | Waterbury† 1905-6 | Gloversville*aa* 1908-9 | Worcester 1908 | Chicago (39th St.) 1909-12 | Chicago (Stockyards) 1913. Day Sewage |
| Nitrogen as— | | | | | | | |
| Organic Nitrogen | 9.1 | 9.0 | 14.8 | 23.0 | ........ | 7.8 | 79 |
| Free Ammonia | 13.9 | 11.0 | 7.8 | 12.0 | 22.2 | 9.1 | 22 |
| Nitrites | 0.0 | 0.09 | 0.14 | 0.38 | ........ | 0.10 | 0.49 |
| Nitrates | 0.20 | 0.20 | 1.52 | 0.88 | ........ | 0.33 | 3.04 |
| Oxygen Consumed | 56** | 51†† | 46** | 95** | 117 | 43 | 268 |
| Chlorine | 2300() | 65 | 48 | 158 | 57 | 40 | 1100 |
| Suspended Matter | | | | | | | |
| Total | 135 | 209 | 165 | 406 | 258 | 144 | 605 |
| Volatile | 91 | 79 | 115 | 229 | 166 | 90 | 461 |
| Fixed | 44 | 130 | 50 | 177 | 92 | 54 | 144 |
| Alkalinity | 125 | 350 | 41 | 233 | ........ | 212 | 291 |
| Fats | ........ | 25 | 26 | 48 | ........ | ........ | ........ |

* From Winslow and Phelps, "Investigation on the Purification of Boston Sewage in Septic Tanks and Sprinkling Filters," Technology Quarterly, Vol. XX, No. 4, p. 410, Dec., 1907.

*a* Geo. A. Johnson, Report on Sewage Purification at Columbus, O., pp. 26, 34.

† From W. Gavin Taylor, "Waterbury Sewage and Its Septic Action," Eng. News, Vol. 61, p. 59.

††Sample immersed in boiling water for 30 minutes.

**Sample boiled for 5 minutes.

()Chlorine from Water Supply Paper No. 185, (U. S. Geol. Survey), pp. 111-114.

*aa*Eddy and Vrooman, "Report on Sewage Purification, "Gloversville N. Y., p. 59.

The temperature of the sewage at Center Ave. ranged from 60 deg. Fahr. in the winter to 90 deg. Fahr. in the summer, being nearly 20 deg. warmer than the domestic sewage at 39th St. (Fig. 23).

The average week day flow at Center Ave. sewer, gaged during 11 months in 1912-13 varied from 16.4 cu. ft. per sec. at night to 29.0 cu. ft. per sec. by day with a maximum recorded hourly rate of 105 cu. ft. per sec. during a rainstorm. The Sunday flow has averaged 14.1 cu. ft. per sec. Of this flow about 150,000 gal. per 24 hr. have been handled in the testing station.

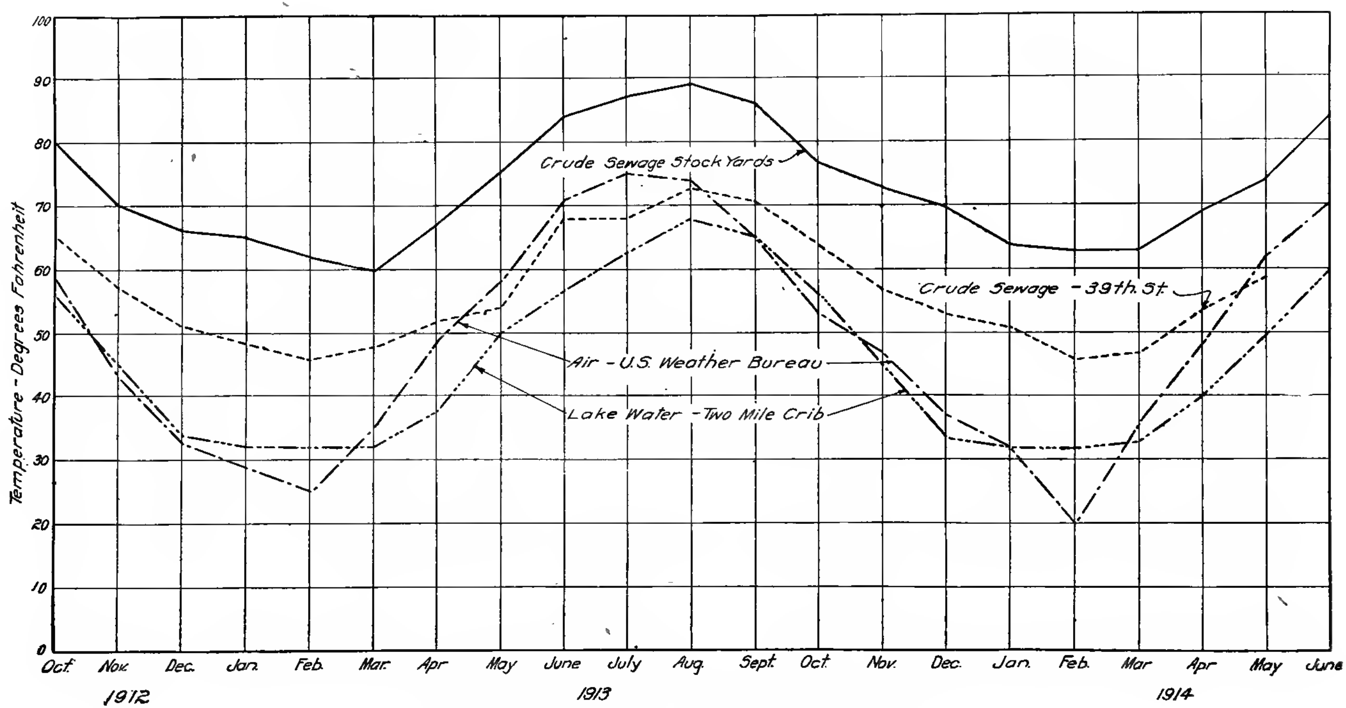


Fig. 23. Temperature of Sewage. Lake and Air.

SCREENING, COARSE. All the crude sewage used in the testing station passed through a bar screen with ⅝ inch clear openings. The retention of solid material was nominal, averaging about 90 lb. of moist screenings per mil. gal. with a moisture content of 82 percent. The screenings are largely hair, coarse vegetable matter, guts and similar material quite foreign to domestic sewage. A coarse screen is requisite in any case to protect pumps and other devices.

GRIT CHAMBER. The grit chamber has been operated at velocities from 17 to 25 ft. per min. With a detention period varying between 50 and 70 sec., the suspended matter has decreased inappreciably, but a slight deposit of detritus largely mineral, has occurred in amount about 0.02 cu. yd. per mil. gal. with a specific gravity of 1.3 and a moisture content of 44 percent. The grit chamber has acted largely as a grease skimmer, from 5 to 1,260 lbs. of scum per mil. gal. having been removed containing on an average about 75 percent moisture. Of the dry residue about 60 percent is ether soluble. This is, however, by no means a complete fat recovery, being less than 11 percent of the total ether soluble. The collection is higher in winter than in summer.

TREATMENT IN SETTLING TANKS. Plain sedimentation was tried in both Dortmund and Emscher tanks, and chemical precipitation in a Dortmund tank. The Emscher tank, at first arranged for a downward and upward flow, was changed on March, 1914, to a straight horizontal flow tank.

A daily average of 49 to 69 percent of the suspended matter in the heavy day sewage can be removed by plain sedimentation in tanks of the Dortmund and Emscher vertical flow types with periods from 1 to 4 hours. The effectiveness of the vertical flow tanks of the Dortmund or Emscher type depends on low velocities. From 60 to 70 percent of the suspended matter can be removed in straight flow Emscher tanks with a period from 2 to 3 hours. Chemical precipitation will remove upwards of 80 percent of the suspended matter, using about 3 grains of iron sulphate and 5 grains of lime per gallon (Table 126).

QUIESCENT SEDIMENTATION. Special experiments on quiescent sedimentation in a deep can along the lines indicated by Steuernagel at Cologne, Germany, show a removal of 76 percent of the suspended matter in 2 hr., with 1,100 p.p.m. present. Extended settling over 12 hr. indicates a removal of 79 percent, which

## TABLE 126

PERCENTAGE REMOVAL OF SUSPENDED MATTER BY VARIOUS DEVICES

| Device | Period of Flow Hours | Veloc. Ft. per Hour | Percent Removal Susp. Matter | | Remarks |
|---|---|---|---|---|---|
| | | | Day Samples | 24-Hr. Samples | |
| Dortmund Tank | 10.0 | 1.0 | 80 | 72 | |
| | 4.0 | 1.1 | 69 | 65 | |
| | 3.0 | 1.5 | 69 | 65 | |
| | 6.0 | 1.7 | 63 | 57 | |
| | 2.0 | 1.8 | 49 | 42 | |
| | 1.9 | 2.3 | 54 | 53 | |
| | 4.0 | 2.6 | 54 | 48 | |
| | 1.0 | 4.5 | 49 | 47 | |
| Emscher Tank | 4.0 | 1.9 | 52 | 45 | |
| | 3.0 | 2.5 | 50 | 47 | |
| | 2.0 | 3.8 | 51 | 48 | |
| | 1.5 | 5.0 | 53 | 50 | |
| | 1.9 | 9.2* | 61 | 58 | *Horizontal Velocity |
| | 2.9 | 6.0* | 72 | 69 | *Horizontal Velocity |
| Chem. Precip. | 3.0 | 3.5 | 76 | 72 | 5.5 gr. Copperas; 10.3 gr. lime |
| | 3.0 | 3.5 | 80 | 77 | 4.5 gr. Copperas; 10.7 gr. lime |
| | 3.0 | 3.5 | 84 | 79 | 3.5 gr. Copperas; 9.9 gr. lime |
| | 2.0 | 2.2 | 78 | 74 | 3.3 gr. Copperas; 8.6 gr. lime |
| | 2.0 | 2.2 | 67 | 68 | 3.5 gr. Copperas; 5.1 gr. lime |
| | 4.0 | 2.6 | 79 | 70 | 3.5 gr. Copperas; 5.1 gr. lime |
| | 4.0 | 2.6 | 82 | 74 | 2.4 gr. Copperas; 5.2 gr. lime |
| | 4.0 | 2.6 | 72 | 65 | 5.2 gr. Copperas; 5.5 gr. lime |
| | 6.0 | 1.7 | 77 | .... | 4.9 gr. Copperas; 6.0 gr. lime |
| | 4.0 | 2.6 | 64 | 52 | 2.4 gr. alum; 2.8 gr. lime |
| | 4.0 | 2.6 | 73 | 66 | 3.0 gr. alum; 0.0 gr. lime |
| | 4.0 | 2.6 | 82 | 76 | 1.9 gr. alum; 2.7 gr. lime |
| | 4.0 | 2.6 | 80 | 76 | 3.2 gr. alum; 0.0 gr. lime |
| Rotary Screen | | | | | |
| 30 Mesh | ...... | ...... | .... | 17 | 8:00 a. m. to 4:00 p. m. |
| 30 Mesh | ...... | ...... | .... | 12 | 7:30 a. m. to 10:00 p. m. |
| 30 Mesh | ...... | ...... | .... | 9 | 8:00 a. m. to 11:00 p. m. |
| Fine Screen | | | | | |
| 6 Mesh | ...... | ...... | .... | 13 | |
| 10 Mesh | ...... | ...... | .... | 10 | |
| 16 Mesh | ...... | ...... | .... | 17 | |
| 20 Mesh | ...... | ...... | .... | 16 | |
| 24 Mesh | ...... | ...... | .... | 21 | |
| 30 Mesh | ...... | ...... | .... | 20 | |
| 40 Mesh | ...... | ...... | .... | 26 | |
| Slotted Plates | | | | | |
| Coarse | ...... | ...... | .... | 14 | |
| Medium | ...... | ...... | .... | 20 | |
| Fine | ...... | ...... | .... | 25 | |

NOTE:—Fine screen and slotted plate results are on special runs, not 24-hr., but short.

## TABLE 127

DORTMUND TANK. REMOVAL OF SUSPENDED MATTER

| Upward Average Velocity Ft. per Hr. | Detention Period Hours | Percent Removal Suspended Matter | | Number of Months Averaged | Tank |
|---|---|---|---|---|---|
| | | Day Sewage | Night Sewage | | |
| 4.5 | 1.0 | 49 | 47 | 1 | C |
| 2.6 | 4.0 | 54 | 48 | 2 | D |
| 2.3 | 1.9 | 54 | 53 | 4 | C |
| 1.8 | 2.0 | 49 | 42 | 1 | C |
| 1.7 | 6.0 | 63 | 57 | 3 | D |
| 1.5* | 3.0* | 72* | 67* | 2* | C |
| 1.1 | 4.0 | 69 | 65 | 3 | C |
| 1.0 | 10.0 | 80 | 72 | 1 | D |

*One month on raw sewage and one month on screened sewage in day time.

may be taken to represent the settling suspended matter. The results indicate higher removals than for similar experiments on 39th St. sewage.

DORTMUND TANKS. The Dortmund tanks have been operated at varying detention periods and velocities, with average removal of suspended matter given in Table 127.

These results show that in a Dortmund type of tank, both velocity and detention period are factors in the efficiency of removal of suspended matter. Low velocity is more important than a long period, as the same detention period gives greater efficiencies with the lower velocities. This is of great importance in determining the economy of this type of tank. For instance, with a velocity of 1 ft. per hr. the removal is considerably higher than with velocities of 2.5 ft. and over. As the settling efficiency depends on the velocity, and the capacity on the area multiplied by the velocity, high velocities are desirable from the viewpoint of economy, but undesirable from the standpoint of efficiency.

EMSCHER TANK. With the Imhoff tank, results were obtained as given in Table 128.

**TABLE 128**

IMHOFF TANK. REMOVAL OF SUSPENDED MATTER

| Average Upward Velocity Ft. per Hr. | Detention Period Hours | Percent Removal Suspended Matter | | Number of Months Averaged |
|---|---|---|---|---|
| | | Day Sewage | Night Sewage | |
| ORIGINAL TANK—VERTICAL FLOW | | | | |
| 1.9 | 4.0 | 52 | 45 | 2.5 |
| 2.5 | 3.0 | 50 | 47 | 2.0 |
| 3.8 | 2.0 | 51 | 48 | 5.5 |
| 5.0 | 1.5 | 53 | 50 | 4.0 |
| REMODELLED TANK—HORIZONTAL FLOW | | | | |
| 9.2* | 1.9 | 61 | 58 | 2.3 |
| 6.0* | 2.9 | 72 | 69 | 3.0 |

*Horizontal Vel. Ft. per Hr.

Less variation occurred for different periods and velocities than with the Dortmund tanks. The relatively high efficiency for the 1½ hr. detention period may have been influenced by the addition of scum baffles about that time, which retained considerable light floating material from passing off in the effluent. The dis-

turbances incidental to "ripening" of the sludge digestion chamber, also interfered with the efficiency of the tank during the first few months of operation.

CHEMICAL PRECIPITATION. With chemical precipitation using copperas or alum and lime, or alum alone, during the hours of strong flow, and plain sedimentation during the night, a reduction in suspended matter of about 80 percent was secured (Table 129).

**TABLE 129**

CHEMICAL PRECIPITATION. REMOVAL OF SUSPENDED MATTER

| Upward Vel. Ft. per Hr. | Detention Period Hr. | Grains per Gal. | | Percent Reduction | |
|---|---|---|---|---|---|
| | | Copperas | Lime | Day | 24-Hour |
| 3.3 | 3.0 | 5.5 | 10.3 | 76 | 72 |
| 3.3 | 3.0 | 4.5 | 10.2 | 80 | 77 |
| 3.3 | 3.0 | 3.5 | 9.9 | 84 | 79 |
| 2.2 | 2.0 | 3.3 | 8.6 | 78 | 74 |
| 2.2 | 2.0 | 3.5 | 5.1 | 67 | 68 |
| 2.5 | 4.0 | 3.5 | 5.1 | 79 | 70 |
| 2.5 | 4.0 | 2.4 | 5.2 | 82 | 74 |
| 2.5 | 4.0 | 5.2 | 5.5 | 72 | 65 |
| 1.7 | 6.0 | 4.9 | 6.0 | 77 | .... |
| 2.6 | 4.0 | 2.4* | 2.8 | 64 | 52 |
| 2.6 | 4.0 | 3.0* | 0.0 | 73 | 66 |
| 2.6 | 4.0 | 1.9* | 2.7 | 82 | 76 |
| 2.6 | 4.0 | 3.2* | 0.0 | 80 | 76 |

*Alum Used Instead of Copperas

The apparatus for mixing and applying the chemicals was somewhat crude. In a large installation at least 3 gr. per gal. of copperas and 5 of lime would probably be required. Lime is essential to obtain a floc with the copperas. With alum a floc was formed without the addition of lime but scum formation was excessive. The cost for chemicals alone was assumed at $0.50 per mil. gal. for each grain of lime per gallon, $0.65 for each grain of copperas, and $1.15 for each grain of alum. On the basis given 3 gr. per gal. of copperas would cost $1.95 per mil. gal. and 5 gr. per gal. of lime would cost $2.50 per mil. gal., making a total chemical cost alone of $4.45 per mil. gal.

SLUDGE ACCUMULATION. The amount of sludge retained in the various devices varied considerably per unit volume for individual measurements, apparently due to fluctuations in water content, slight changes influencing the volume very markedly. The relative proportion of bottom sludge and top scum is also a factor of importance. Table 130, based on actual measurements, indicates the amounts of sludge found in cubic yards per million gallons of sewage.

## TABLE 130

SLUDGE ACCUMULATION IN VARIOUS DEVICES

| Tank | Cu. Ft. per Mil. Gal. | | | Period of Observation |
|---|---|---|---|---|
| | Sludge | Scum | Sludge and Scum | |
| Dortmund C | 3.1 | 2.7 | 5.8 | June 24, 1913 to June 19, 1914 |
| Dortmund D | 6.1 | 3.5 | 9.6 | Sept. 16, 1912 to July 7, 1913 |
| Imhoff E | 6.8 | 1.3 | 8.1 | Sept. 16, 1912 to June 1, 1914 |
| Chem. Precip | 12.7 | ...... | 12.7 | Aug. 28, 1913 to June 1, 1914 |

The figure for chemical precipitation is the average of individual runs using copperas and lime, the others are cumulative averages over long periods. With alum instead of copperas, considerable scum formed but those results are not included in the table. The scum accumulation in the Emscher tank is high because of the inclusion of the scum removed during the ripening period At that time it formed in large amounts, but afterwards very much less accumulated. These figures were obtained with a uniform rate of flow through the tanks throughout the entire 24 hours. But as the day flow in the sewer is much greater than the average flow during the hours of flow when the sewage is strongest and consequently when the deposition is greatest, in adapting these figures to actual design, operating conditions must be taken into account. For uniform flow the figures are correct, but for a variable flow through a given number of units allowance must be made for the greater proportion of day flow, in figuring the probable rate of sludge accumulation. On the other hand, the greater depth of the tanks in an actual plant would have a tendency to compact the sludge and thus diminish its volume.

## TABLE 131

ANALYSES OF SLUDGE AND SCUM

| Tank | Specific Gravity | Percent Moisture | Percentage on Dry Basis | | | |
|---|---|---|---|---|---|---|
| | | | Nitrogen | Volatile Matter | Fixed Mat. | Ether Sol. |
| SLUDGE | | | | | | |
| Dortmund C | 1.02 | 90.8 | 2.65 | 72 | 28 | 8.1 |
| Dortmund D | 1.02 | 91.7 | 2.88 | 76 | 24 | 8.6 |
| Emscher | 1.02 | 91.4 | 2.75 | 64 | 36 | 6.6 |
| Chem. Precip | 1.03 | 89.5 | 2.21 | 58 | 42 | 5.1 |
| SCUM | | | | | | |
| Dortmund C | 1.02 | 84.1 | 2.55 | 71 | 29 | 7.7 |
| Dortmund D | 1.02 | 84.5 | 2.60 | 75 | 25 | 9.2 |
| Emscher | 1.01 | 84.1 | 2.73 | 72 | 28 | 12.9 |

Table 131 gives approximately the average composition of sludges and scum from the various tanks.

The digestion in the Emscher tank is shown by the decrease in the proportion of volatile matter over the fresh Dortmund sludges. The influence of the precipitant on the chemical precipitation sludge is indicated by the high ratio of fixed matter. The scums are very similar to the sludges from the respective tanks, except that the moisture content is lower. The Emscher scum, however, shows an appreciably higher percentage of volatile matter, indicating that little or no digestion has occurred.

SCUM. Scum consistently persisted on the surface of the Dortmund tanks at all times. Practically none formed on the chemical precipitation tank, except when alum was used instead of copperas. For the first seven months of operation, scum formation was excessive on the Emscher tank. With the establishment of thorough ripening, however, the production of scum has shown a marked decrease, particularly during the summer months. Experiments on Tank C, using the effluent from the rotary screen, seemed to indicate that scum formation could be largely eliminated by preliminary fine screening through 30 mesh screens.

ODOR. Slight odor developed from the Emscher tank. A trace of hydrogen sulphide was occasionally noted, particularly when sludge was being removed. With the other tanks the odor has been more marked, particularly during the removal of sludge.

SCREENING, FINE. A number of experiments were conducted on the efficiency of fine mesh screens of mesh from 4 to 40 per lineal inch (Table 132). In most cases the flow was 14,800 gal. per 24 hr. per sq. ft, of screen area, on a screen approximately 3.5 sq. ft. in area, on strong day sewage running to a final loss of head of 4.5 ft. From 134 to 1,534 lb. of dry material was removed per mil. gal. (Table 133), with a calculated percent reduction of suspended matter ranging from 10 to 26 percent. The removal by the 24, 30 and 40 mesh screens averaged from 1,098 to 1,534 lb. of dry material per mil. gal. 60, 80 and 100 mesh screens tested subsequently gave somewhat higher percent removals of suspended matter, but as the sewage at that time was weaker the pounds of dry material removed per mil. gals. was less than for the former screens previously tested. These results (Table 133) indicate in general an increasing efficiency with decreasing size of mesh, under similar conditions (Fig. 24).

## TABLE 132

FINE SCREENS. LOSS OF HEAD EXPERIMENTS

DRY SCREENINGS—POUNDS PER MILLION GALLONS AND PER SQUARE FOOT BEFORE CLOGGING

| Size of Screen Nom. Mesh | Rate Gal. per Sq. Ft. per 24 Hr. | Individual Runs | | | | | | | Maximum | Minimum | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DRY SCREENINGS IN POUNDS PER MILLION GALLONS | | | | | | | | | | | |
| 4 | 14,800 | 139 | 124 | 140 | ........ | ........ | ........ | ........ | 140 | 124 | 134 |
| 6 | 14,800 | 715 | 450 | 545 | 805 | ........ | ........ | ........ | 805 | 450 | 654 |
| 10 | 14,800 | 353 | 313 | 687 | 535 | 330 | 307 | ........ | 687 | 313 | 421 |
| 16 | 14,800 | 1386 | 847 | 1010 | 725 | ........ | ........ | ........ | 1386 | 725 | 992 |
| 20 | 14,800 | 915 | 1010 | 1100 | 650 | ........ | ........ | ........ | 1100 | 650 | 919 |
| 24 | 14,800 | 1350 | 1055 | 842 | 1205 | ........ | ........ | ........ | 1350 | 842 | 1113 |
| 30 | 6,840 | 865 | 758 | 705 | ........ | ........ | ........ | ........ | 865 | 705 | 776 |
| 30 | 14,800 | 1050 | 1085 | 1060 | 1910 | 1030 | 1420 | ........ | 1910 | 1030 | 1259 |
| 40 | 14,800 | 2410 | 1530 | 1225 | 1260 | 1390 | 1760 | 2140 | 2410 | 1225 | 1674 |
| 40 | 6,840 | 1055 | 1095 | 2145 | 1863 | ........ | ........ | ........ | 2145 | 1055 | 1290 |
| DRY SCREENINGS IN POUNDS PER SQUARE FOOT BEFORE CLOGGING | | | | | | | | | | | |
| 4 | 14,800 | 0.51 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 0.51 |
| 6 | 14,800 | 0.17 | 0.23 | 0.28 | 0.22 | ........ | ........ | ........ | 0.28 | 0.17 | 0.23 |
| 10 | 14,800 | 0.38 | 0.38 | 0.16 | 0.21 | 0.32 | 0.23 | ........ | 0.38 | 0.16 | 0.28 |
| 16 | 14,800 | 0.22 | 0.25 | 0.10 | 0.13 | ........ | ........ | ........ | 0.25 | 0.10 | 0.18 |
| 20 | 14,800 | 0.06 | 0.10 | 0.10 | 0.13 | ........ | ........ | ........ | 0.13 | 0.16 | 0.10 |
| 24 | 14,800 | 0.11 | 0.09 | 0.06 | 0.16 | 0.14 | 0.13 | ........ | 0.16 | 0.06 | 0.11 |
| 30 | 14,800 | 0.08 | 0.09 | 0.07 | 0.17 | ........ | ........ | ........ | 0.17 | 0.07 | 0.10 |
| 30 | 6,840 | 0.31 | 0.14 | 0.08 | ........ | ........ | ........ | ........ | 0.31 | 0.08 | 0.18 |
| 40 | 14,800 | 0.14 | 0.08 | 0.06 | 0.08 | 0.07 | 0.09 | 0.09 | 0.14 | 0.06 | 0.09 |
| 40 | 6,840 | 0.04 | 0.06 | 0.07 | 0.09 | ........ | ........ | ........ | 0.09 | 0.04 | 0.07 |

NOTE:—Final Loss of Head—4.5 feet exceot for No 4 screen on two runs

## TABLE 133

REMOVAL BY FINE MESH SCREENS

| No. Meshes per Lineal Inch | Net Length of Opening Inches | Dry Screenings Lb. per Mil. Gal. | Susp. Mat. Percent Reduction | No. of Tests |
|---|---|---|---|---|
| 4 | 0.198 | 134 | .... | 3 |
| 6 | 0.137 | 654 | 13 | 5 |
| 10 | 0.072 | 421 | 10 | 6 |
| 16 | 0.042 | 992 | 17 | 4 |
| 20 | 0.036 | 919 | 16 | 4 |
| 24 | 0.029 | 1113 | 21 | 5 |
| 30 | 0.022 | 1098 | 19 | 10 |
| 40 | 0.015 | 1534 | 26 | 11 |

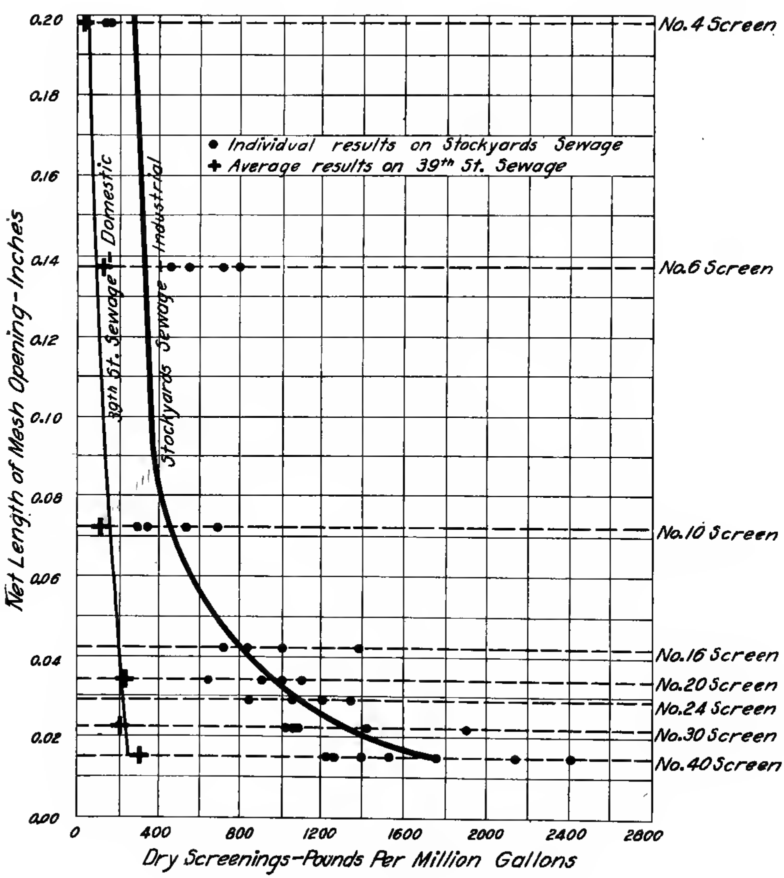


Fig. 24. Removal by Fine Screens.

ROTARY SCREEN. Extended experiments were also made with a small rotary screen of the Weand type, 2 ft. 4 in. in diameter and 4 ft. 8 in. long, swung on a steel axle. The coarse supporting screen was covered with a fine screen of 30 meshes per lineal inch. The screen rotated 7 r.p.m. and was cleaned by a spray of water directed against the outside, the screenings being ejected at one end by a worm and buckets. During three separate runs in October, November and December, 1913; May, 1914, and June, 1914, each of about one month's duration, the results given in Table 134 were obtained.

**TABLE 134**

REMOVAL BY ROTARY SCREEN

| Date | Hours of Operation | Dry Screenings Lb. per Mil. Gal. | | | Percent. Reduction Susp. Mat. Computed | | |
|---|---|---|---|---|---|---|---|
| | | Max. | Min. | Avg. | Max. | Min. | Avg. |
| Oct. to Dec. 1913 | 8:00 a. m. to 4:00 p. m. | 1420 | 505 | 950 | 23 | 12 | 17 |
| May 1914 | 7:30 a. m. to 10:30 p. m. | 816 | 304 | 500 | 16 | 6 | 12 |
| May 1914 | 10:30 p. m. to 7:30 a. m. | 41 | 26 | 32 | .... | .... | .... |
| July 1914 | 8:00 a. m. to 11:00 p. m. | 488 | 194 | 319 | 12 | 6 | 9 |

Based on the actual analyses, the average reduction of suspended matter for the first run was about 32 percent, as compared with the average of 17 percent, computed by the addition of the weight of screenings to the effluent. The result of operation during the heaviest hours of the day is strikingly shown. Extending the period of operation into the evening cuts down the unit rate of accumulation, while the removal at night is comparatively low. The capacity of the screen was not found to be exceeded with the rates of flow between 5,300 and 8,000 gal. per day per sq. ft. of net effective area, at the linear peripheral velocity of 51 ft. per min.

SCREENINGS. The material caught by the screen differs widely in appearance from the tank sludges and scums, and is usually of a dirty greenish yellow color, firm enough as ejected to be forked after slight draining. The material is largely organic, the volatile matter in the dried residue running uniformly over 90 percent. When delivered from the screen, the moisture content averages between 85 and 88 percent, but after slight draining is readily reduced to about 80 percent.

SCREENS ON STOCKYARDS AND PACKINGHOUSE. Beside the work at the testing station, additional tests were made on a traveling band screen designed by Mr. C. A. Jennings, located at the outlet of the Morgan Street sewer, and also on a Weand screen, purchased by the packers and installed at the Sulzberger plant. The Morgan Street sewer receives drainage from a portion of the stockyards only. The sewage is considerably weaker than the ordinary packing wastes. The Sulzberger screen was set up at the outlet for the entire plant. Both these screens were covered with wire cloth with 40 meshes per lineal inch when tested. The duration of each test at Sulzberger's was from 1 to 7 hr., according to circumstances and from 5 to 6 hr. at Morgan Street (Table 135).

**TABLE 135**

REMOVAL BY SCREENS AT MORGAN ST. AND SULZBERGER'S

| Sewer Outlet | Dry Screenings Lb. per Mil. Gal. | | | Percent Reduction Suspended Matter | | | No. of Tests | Screen |
|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Avg. | Max. | Min. | Avg. | | |
| Morgan St. | 1420 | 945 | 1150 | 49 | 22 | 33 | 5 | Jennings |
| Sulzberger* | 2830 | 320 | 1690 | 39 | 8 | 26 | 7 | Weand |

*Now known as Wilson and Co.

The initial content of suspended matter delivered to the Jennings screen averaged 340 p.p.m., whereas that at the Sulzberger plant averaged 747 p.p.m. Considerably higher efficiencies are probably possible at the individual plants than can be obtained at the Center Ave. outfall, largely because of the greater concentration and freshness of the wastes. Although no tests were made by the District at the Armour plant, an average efficiency of about 65 percent was claimed by their superintendent, Mr. Harding. This appears very high, but may be influenced by concentrated waste from certain processes, as for instance, water from the paunch manure presses containing considerable coarse material in suspension.

An essential requisite of a good screen is its equipment with adequate cleaning devices. Water was used on the screen at the testing station and compressed air on the Jennings screen. Both were effective, but the high pressure at which the air was then applied resulted in rapid destruction of the wire mesh. The presence of large quantities of grease or fat in the sewage is likely to cause more or less clogging, by depositing or chilling in the meshes of the screen. This can be removed by occasional application of steam.

# TABLE 136

## FINE SCREEN FOLLOWED BY PLAIN SEDIMENTATION IN DORTMUND TANK (TANK C)

Reduction in Suspended Matter Using Screened Sewage in Daytime with Detention Period of 3.0 Hours and Upward Vel. of 1.5 Ft. per Hr.

| Day July 1914 | Day Sewage | | | | | | Night Sewage | | | Day and Night Sewage | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Suspended Matter Parts per Mil. | | | Percent Reduction | | | Susp. Matter Parts per Mil. | | Percent Reduction | Suspended Matter Parts per Mil. | | | Percent Reduction | | | Screenings P.P.M. |
| | Screen Infl. p | Screen Effl. f | Tank Effl. f | Screen | Tank | Total | Infl. | Effl. | | Screen Infl. s | Screen Effl. s | Tank Effl. | Screen | Tank | Total | |
| 6 | 527 | 475 | 105 | 10 | 70 | 80 | 102 | 38 | 63 | 368 | 335 | 80 | 9 | 69 | 78 | 52 |
| 8 | 349 | 306 | 93 | 12 | 61 | 73 | 100 | 16 | 84 | 256 | 229 | 64 | 11 | 64 | 75 | 46 |
| 10 | 374 | 340 | 91 | 9 | 67 | 76 | 52 | 76 | 46* | 253 | 232 | 85 | 8 | 58 | 66 | 34 |
| 13 | 326 | 301 | 76 | 8 | 69 | 77 | 22 | 50 | 56 | 212 | 196 | 66 | 8 | 61 | 69 | 25 |
| 15 | 671 | 632 | 115 | 6 | 77 | 83 | 122 | 116 | 5 | 465 | 441 | 115 | 5 | 70 | 75 | 39 |
| 17 | 413 | 378 | 133 | 9 | 59 | 68 | 106 | 84 | 21 | 298 | 276 | 115 | 7 | 54 | 61 | 35 |
| 20 | 570 | 542 | 238 | 5 | 53 | 58 | 72 | 44 | 39 | 383 | 366 | 165 | 5 | 52 | 57 | 28 |
| 24 | 557 | 515 | 72 | 8 | 79 | 87 | 68 | 44 | 35 | 374 | 347 | 62 | 7 | 76 | 83 | 42 |
| 27 | 518 | 468 | 104 | 10 | 70 | 80 | 112 | 48 | 57 | 366 | 335 | 83 | 9 | 68 | 77 | 50 |
| 29 | 591 | 550 | 79 | 7 | 80 | 87 | 200 | 40 | 80 | 444 | 419 | 64 | 5 | 81 | 86 | 41 |
| Average | 497 | 451 | 111 | 9 | 69 | 78 | 96 | 56 | 42 | 342 | 318 | 90 | 7 | 67 | 74 | 39 |

NOTE:—* Denotes increase
s Screen run from 8 a.m. to 11 p.m. only
p Computed from effluent analyses and screenings
f Corrected for dilution by wash water
Individual samples cover 2 days, including date noted. Sundays omitted

At Morgan St. the 40 mesh screen removed from 4,820 to 7,860 lb. per mil. gal. wet material, averaging 6,740 lb. or 1,150 lb. dry. This removal averages about 24 percent actual suspended matter or a computed removal of 33 percent. The previous summer a small straight flow tank of 1.21 hr. capacity removed 3.8 cu. yd. of sludge per mil. gal. of 88.5 percent moisture. The removal of suspended matter averaged 63.8 percent, with an average of 548 p.p.m. in the influent. This yardage is probably low because the tank unloaded at times. The sludge had an offensive putrid odor. Based on the removal of suspended matter, the sedimentation plant is far more effective than screening.

SCREENS WITH TANKS. As an adjunct to tank treatment, fine screening is likely to prove useful. The removal of light scum forming material from the influent to the tanks is desirable in reducing operation difficulties and increasing the clarity of the effluent. During the months of May and July, 1914, one tank was operated on screened sewage during the daytime (Table 136), and maintained almost an entire freedom from scum throughout the month. Under ordinary operation, a heavy scum would have formed long before the end of the month. The reduction in amount of sludge handled is also desirable under the conditions existing in the yards. Screenings at the rateof 500 lb. of dry material per mil. gal. would represent a reduction in volume of nearly 3 cu. yd. of sludge containing 90 percent moisture or about 2 cu. yd. of scum containing 85 percent moisture.

SLUDGE HANDLING. The handling of the liquid sludge produced by settling tanks is one of the important factors in reaching a conclusion. The rate of accumulation of sludge from the various devices was large and the composition largely organic.

When withdrawn from the tanks in bulk, the moisture content was always greater than that in situ, as the withdrawal of some of the overlying sewage appeared almost inevitable, on a small scale. This increased the volume to be handled. The sludge from the various devices differed in appearance. That from the Emscher tank was uniformly black and even-grained, flowing readily and had little or no odor. The fresh sludge from plain sedimentation was usually of a dirty greenish black color, frequently having a very offensive odor. The consistency when run from the tank was not uniform, sometimes being very thick, while at other times quite thin. The chemical precipitation sludge was

usually of a dirty greenish black or deep black color, sticky in consistency, and ordinarily had a peculiar sickish or metallic odor. The sludge from the secondary settling basin was usually of a deep brown color, very smooth in appearance, with an odor resembling that of decayed vegetables.

SLUDGE DRYING. Experiments on underdrained sand beds showed that the Emscher tank sludge uniformly dried to a spadeable condition in layers 1 to 1.5 ft. thick in 5 or 6 days of good weather. Under these circumstances the moisture content was ordinarily reduced to about 75 percent. Although the sludge was still moist, it was removed from the beds without difficulty. With fresh Dortmund sludge dried under similar conditions, the drying time varied from 2 to 4 weeks with a final moisture content of about 75 percent. The chemical precipitation sludge was even more retentive of moisture, 3 to 4 weeks being required.

The Emscher sludge drained largely from beneath. Within 24 hours after application, the surface became firm and cracks began to appear. With the fresh sludge, the water ordinarily flushed to the surface, making the drying largely a matter of surface evaporation. The chemical precipitation sludge was very retentive of moisture, a thin hard crust forming on the surface, while the interior of the mass remained soft and sticky for long intervals. Violent septic action was sometimes noted in this sludge after application to the beds, the surface sometimes falling 6 in. on the stirring of the mass, by the liberation of entrained gases.

Little has yet been done on the secondary settling basin sludge, but the indications are that it will dry very readily in thin layers.

The beds used in these experiments were about 6 in. deep, consisting of graded gravel overlaid with about 1 to 2 in. of torpedo sand. They were exposed to the sun and air.

SLUDGE PRESSING. A few experiments were made with a Kelly filter press, using the chemical precipitation and fresh sludges. Sludge was pumped into the press under pressure of from 70 to 80 lb. per sq. in., which were maintained for about 15 min., the filtrate escaping through the press cloth. Irrespective of the initial moisture content, a final result of about 75 percent was obtained in most cases. The sludge appeared wetter than that of similar moisture content removed from the beds, being more compact. One objection to this type of apparatus was found to be

the frequent rehandling of sludge necessary, as the cloths became completely clogged after a thin "cake" had formed over them. The interior of the press was left filled with liquid sludge which had to be withdrawn to allow the cloths to be cleaned.

SLUDGE FUEL VALUES. Calorific tests showed various sludges to have thermal values varying from 2,500 b.t.u. per lb. for dried sludges, which had been exposed to the weather for several months, to over 9,000 b.t.u. per lb. for fresh sludges and screenings on a dry basis. The fresh material, if rapidly dried, has a calorific value comparable to that of poor coal when computed on a dry basis. A considerable portion of these heat units must, however, be used in evaporating the moisture content. A considerable loss of heat producing constituents occurs, however, on protracted exposure to the air. The great bulk of water which the fresh sludges contain is the chief obstacle to their incineration.

FERTILIZER VALUES. The few analyses for fertilizing constituents made do not promise recovery of any fertilizer values worth attention from a standpoint other than possible reduction of sludge volume.

SPRINKLING FILTER. The filter was 6 ft. in depth, consisting of 5 ft. 6 in. of 1¼ to 2 in. limestone overlying 6 in. of 2 to 4 in. stone. It was dosed with a Taylor circular spray nozzle with a cam device for regulating the head on the nozzle. The effluent from the Emscher tank was applied to the filter. Operation began in September, 1913, at a nominal rate of 0.75 mil. gal. per acre daily and this rate was maintained till April 1, 1914, when it was increased to 1 mil. gal. per acre. On August 1, the rate was still further increased. These rates are actual net yields.

The work of the filter was very satisfactory. Suspended matter varying between 70 to 210 p.p.m. was applied, the removal varying from about 45 percent to an increase of 76 percent during the unloading period in April, 1914. Nitrification became well established within a few days after the start and has been well maintained since, the nitrates in the effluent varying from 10 to 20 p.p.m. on the average.

Putrescibility and dissolved oxygen samples were taken four times daily at 3 a. m., 3 p. m., 9 a. m. and 9 p. m. The former were incubated at room temperature for 10 days.

For the entire period of the operation of the filter an average relative stability of 73 was obtained. But during May, June and

July, the stability was 94. The time required to ripen, and the spring unloading in April lowered the stability for the first six months. There appears little doubt but that a rate can be maintained of net yield of 1 mil. gal. per acre per 24 hr. on a bed 6 ft. deep, with good results, giving practical stability once the filter has ripened.

The performance of the filter was best emphasized by the reduction in oxygen requirements. Approximately 1,000 p.p.m. of oxygen were required for complete stability of the crude sewage from Center Ave., whereas the average requirement for the filter effluent was about 64 p.p.m. or a reduction of over 90 per cent. The filter effluent contained enough oxygen available to meet this requirement during the past 3 months and was stable. These figures were for the strong day sewage. Free oxygen was nearly always present in the filter effluent which was uniformly clear. The material in suspension discharged by the filter was granular, settling readily.

The indications are that a sprinkling filter can handle this liquid and produce an effluent remarkably improved over the original sewage. Continued operation is needed to settle the question of permanency of capacity. There is evidence that more or less fat is retained at times in the filter. Whether or not this will be removed during the unloading period is a question. Owing to the high temperature of this sewage, cold winter weather is not likely to cause any difficulty in operation.

SECONDARY SETTLING. The effluent from the filter was passed through a small secondary settling basin operated on the Dortmund principle. The detention period was 1 hr. the greater part of the time, and the upward velocity from 2.4 to 3.5 ft. per hr. Under these conditions, the removal of residual suspended solids varied from an increase of 7 per cent to a removal of over 50 per cent, based on monthly averages. A longer period and lower velocity is evidently required. Sludge accumulated at a rate varying from 0.5 to nearly 8.0 cu. yd. per mil. gal. between individual measurements. The percentage of volatile matter in the sludge recovered from this tank was appreciably lower than for the fresh sludges from the premilinary tanks, while the nitrogen content was distinctly higher.

Secondary settling basins appear desirable on account of the large amounts of suspended matter applied to the filter and unloaded. Owing tc the excessive scum formation at times and the

comparative difficulty of maintaining single chamber tanks, a double-deck type of tank seems preferable, even though a shallow sludge chamber necessitates pumping the sludge into the deeper primary settling tanks.

OXYGEN REQUIRED. Comparison of the total oxygen required for the oxidation of the sewage showed a demand at 39th St. on domestic sewage, of about 100 to 150 p.p.m., whereas at Center Ave. the demand was around 1,000 p.p.m. The improvement by plain settling of the Center Ave. sewage averaged from 18 to 48 percent. The sprinkling filter did not at all times deliver a stable effluent, particularly at the start. However, during May, June, and July, 1914, the oxygen available in the effluent was greater than the demand, so the liquid proved thoroughly stable, for the specific tests for biologic oxygen consumed. The large number of relative stability tests made check very closely, with an average relative stability of 94.

The indications are clear that fine screening had a small effect on improving the stability of the liquid, compared with the improvement due to sedimentation.

FAT REMOVAL. While considerable fat is and has been removed by the skimming basins of the various packing houses, and on the Center Ave. and Ashland Ave. outlets, there is a loss due to insufficient basin capacity. The fat contained in the sediment or sludge is also lost, as well as the fats which are kept in an emulsified state in the hot summer sewage, by the heat of the liquid.

The studies on fat removal show a greater removal in the winter than the summer. This is not explicable on the theory of lack of business in summer, but probably depends on temperature. The melting point of the fat extracted by ether from the fatty wastes collected by us is 26 deg. C. or 79 deg. F. In the summer months the sewage is continuously warmer in the day. Cooling the sewage by exposure to air in shallow basins, or artificially seems to be the probable solution of this problem. About half the fat was removed on the average by plain sedimentation, while with chemical precipitation about two-thirds was deposited.

RECOVERY OF FAT BY ACIDIFICATION. Although there is considerable fat reported in the sludges as directly ether soluble, yet the acidification of the sludge will in many cases greatly increase the fat yield Several random analyses are given on both sludge and scum:

| Tank | Material | Ether Soluble Percentage of Dry Weight | | Remarks |
|---|---|---|---|---|
| | | As Removed | Acidified | |
| C | Scum | 11.4 | 23.3 | Chem. Precipn. |
| D | Sludge | 7.4 | 10.0 | Bottom Sludge |
| C | Sludge | 10.0 | 25.6 | |
| Grit Cham | Scum | 62.3 | 69.0 | |
| E | Scum | 12.6 | 29.8 | From Gas Vent |

Acidification of the heavy day sewage followed by sedimentation for 3 hr. in a Dortmund tank gave an average fat removal of about 69 per cent. The amount of acid consumed is large, 2,500 lb. of 100 percent sulphuric acid per mil. gal. being necessary to neutralize the alkalinity, while for efficient fat removal an excess is required.

Acidification of the sludge removed by plain sedimentation with subsequent recovery of the grease by the use of some solvent or by distillation with steam is also a possibility. The processes and costs are not as yet established.

Various ways have been suggested of acidification, which if ever proved economical, can readily be added to settling works. Acidification of sewage makes an apparent reduction in the biologic oxygen consumption which is remarkable, but this is probably not real, being simply due to a retardation of decomposition by the sterilization of the bacteria present; the organic material being left in solution. If thoroughly seeded, new bacteria will pick up the work of decomposition, the liquid then proving putrescible. Similar phenomena may happen with chloride of lime.

GENERAL CONCLUSIONS. The operation of the Center Ave. testing station has demonstrated that it is entirely practicable to treat to any desired degree sewage, mixed from industrial and domestic origin, as it issues from the Center Ave. outlet. Of the devices tried, fine screening, sedimentation in double-deck tanks, and sprinkling filters appear most suitable. The combinations are:

1. Fine screening.
2. Fine screening in combination with sedimentation.
3. Fine screening in combination with sedimentation followed by biological treatment on sprinkling filters and secondary sedimentation.

Under any circumstances the removal of settling suspended matter from industrial wastes is needed. Fine screening alone

does not appear adequate to meet this test. In almost every case screens can be installed at the individual houses, and on the fresh sewage will undoubtedly be more effective. Hence, screening appears to be an individual problem for each house or firm. Sedimentation requires more space, both for equipment and disposal of sludge and hence is best handled as a community problem because at most houses space is lacking.

In any case, fine screening is the logical first step to remove the coarse suspended matter and will fit with sedimentation in that it materially reduces the scum-forming material.

Ultimately biological treatment of industrial wastes is a necessity. Sprinkling filters followed by secondary settling tanks seem most desirable. But with a gradual installation, opportunity is afforded on a large scale to watch the effect of the removal of suspended matter from a gross source of pollution. Preliminary screening and settling are necessary as a preparatory treatment for sprinkling filters and would be advantageous in the operation of a long intercepting sewer by preventing deposits from a sewage so heavily laden with settling suspended matter.

OBJECT OF INVESTIGATION. The purpose of the investigation has been two-fold, first to learn how to relieve the load upon the main channel coming from the organic waste of this industry and second how to remove the local nuisance from the East and West arms of the South Fork of the South Branch of the Chicago River, and particularly the West arm, known popularly as Bubbly Creek.

CONSIDERATIONS INVOLVED. The solution of the problem involves not only a consideration of the municipal and private sewers in and around the yards and Packingtown, but also the efficiencies of various forms of treatment, the size and location of treatment works, and the relation of different steps in the collection and treatment to the future. Whatever is done must be flexible, readily adapted to future extension and fitting into a comprehensive system, if it ever becomes necessary.

EXISTING SEWERS. The present system of private sewers in Packingtown is generally inadequate for flood flows. Center Ave. sewer is also overloaded at time of heavy rain. The City of Chicago is now planning a new sewer, located to the west of, and parallel to the Center Ave. sewer, to run south and relieve the old

Center Ave., Ashland Ave. and Robey St. sewers and drain some new territory.

EXISTING TREATMENT. At present there is practically no treatment of the industrial sewage from Packingtown other than a partial removal of fat by grease skimming basins. The basins are seldom built to retain settling material, except at the hog-houses and then are insufficient. The screens in use are very coarse, and hold back little except intestines.

At the stockyards, the Jennings screen is handling the outflow of the Morgan Street sewer. At the other outlets no treatment is given.

FILLING BUBBLY CREEK. From the Sanitary standpoint the filling of Bubbly Creek would be desirable, although mere filling alone would simply transfer the nuisance from one locality to another. With suitable treatment of the industrial wastes it is entirely proper that this dead arm be filled and that the area thus reclaimed be used as a site for sedimentation tanks. The areas reclaimable are:

A. From the end of the West arm to Ashland Ave.—11.5 acres.

B. From the end of the West arm to W. 39th St.—16.5 acres.

C. From the end of the West arm to the Forks—24.3 acres.

The fill required can be obtained in part from the construction of the proposed Center Ave. sewer, the proposed sedimentation plant and from the dumping of ashes. The sedimentation plant itself for industrial wastes only will require six acres and a reservation of three acres for future use.

The points to be cared for are:

1. The flow in the West 39th St. conduit should be increased by the introduction of the sewage from Robey St. and industrial sewages from the East thereof including the stockyards and Packingtown.

2. The sewage from the stockyards and Packingtown should be treated by fine screening and sedimentation at once regardless of the outcome of the Federal suit.

3. A portion of the bed of the West arm should be reserved for the sedimentation plant.

4. Intercepting sewers will be required to collect the sewage and to divert the wastes of Packingtown from the new Center Ave. sewer into Ashland Ave.

BEST PROJECT. Consideration of various alternatives (see Chapter XVII) leads to the belief that the best project comprises an intercepting sewer for industrial wastes and domestic sewage extending from Halsted St. to the west end of the West arm, the diversion of all Packingtown sewage from Center Ave. sewer to Ashland Ave. sewer, fine screening at the individual houses or firms, sedimentation at the outlet of the intercepting sewer, in a community plant built in the bed of the West arm west of Ashland Ave., an outfall sewer into the West 39th St. conduit, receiving the effluent of the plant, and the diversion of the Robey St. sewer into the same conduit. The cost of this project is approximately $985,000, exclusive of legal, engineering and land expenses. The new Center Ave. sewer, under this project, would receive no industrial waste from the stockyards or Packingtown.

Such a project for screening and sedimentation handles the waste as separately as possible, with the presence of some domestic sewage, and is flexible with regard to the future.

The ultimate solution will require biological treatment. As space is lacking in the immediate vicinity of Packingtown, this means an extended intercepting sewer running westward from the outfall of the sedimentation plant, which would carry the screened and settled sewage to a pumping station where the sewage would be pumped onto sprinkling filters. The effluent would require settling in secondary settling tanks. Sludge drying beds, an outfall sewer, and other collateral works are required. This fits directly onto the settling plant just described. Screening and sedimentation are necessary as a preliminary treatment, and will materially aid in maintaining the intercepting sewer free from deposits. The additional cost for the intercepting sewer, pumping station, sprinkling filters and collateral works is approximately $3,600,000, exclusive of legal, engineering and land expenses.

BURDEN OF COST. There are many preliminary questions to be solved of legal and financial nature, as well as engineering details before construction can commence. Particularly important is the distribution of the burden of cost. Undoubtedly the law intends that the larger burden shall be carried by the industries, for the organic law of the Sanitary District is based on the theory that a channel will be constructed solely for the reception of domestic wastes.

RECOVERIES. The results of the testing station do not indicate hope of recovering much material of value from the commercial standpoint, other than grease. It is possible that use may be found for the sludge as filler for fertilizer, and that the screenings may be burned. The smaller houses should endeavor to save all offal or other material now reaching the sewers, which is saved by the larger houses, by some co-operative arrangement.

The chief object to attain here is not commercial recoveries, but the destruction of a nuisance long standing. Improved conditions of sanitation, and standards of civic cleanliness demand this.

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IN REPORT

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